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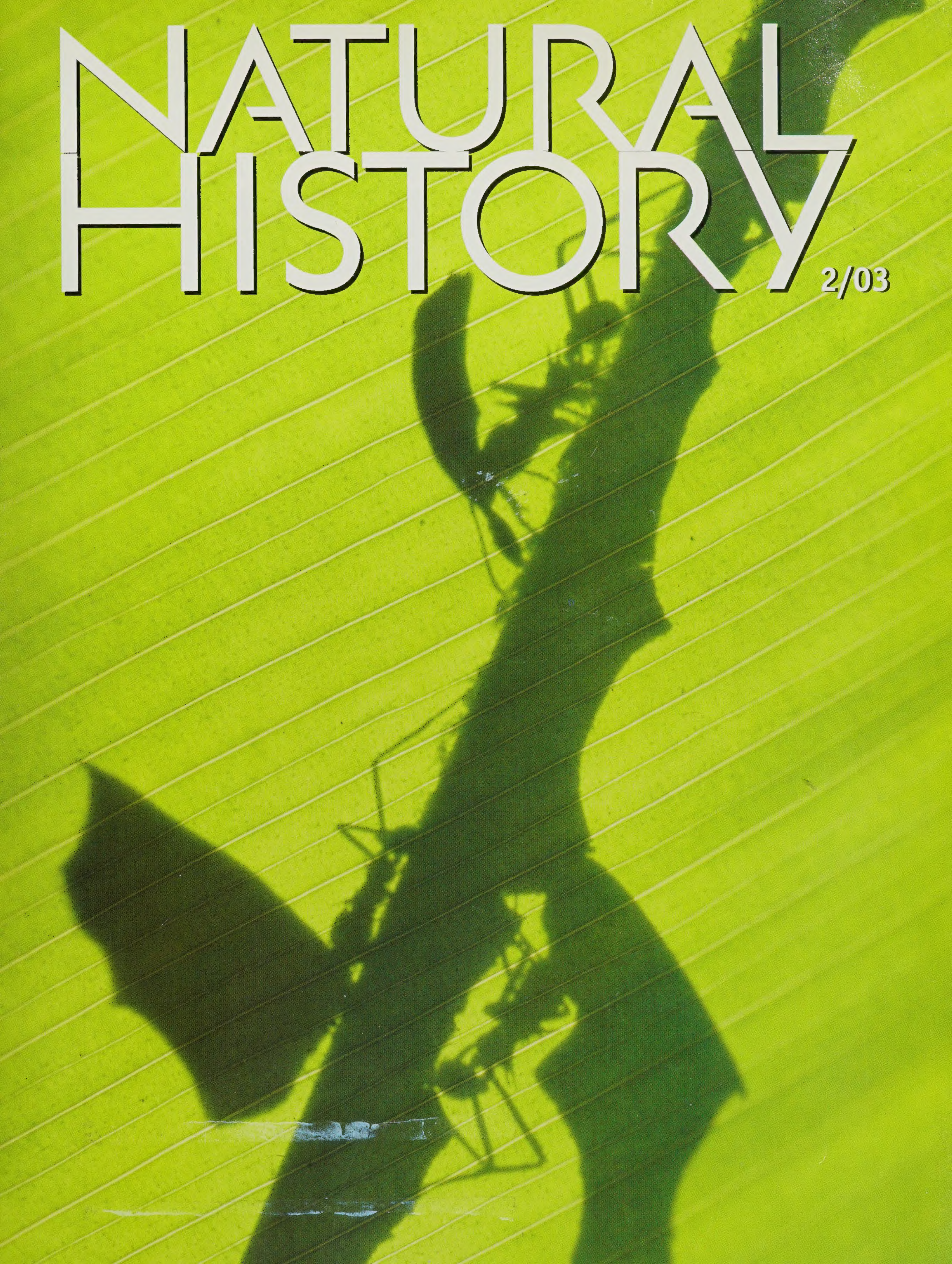

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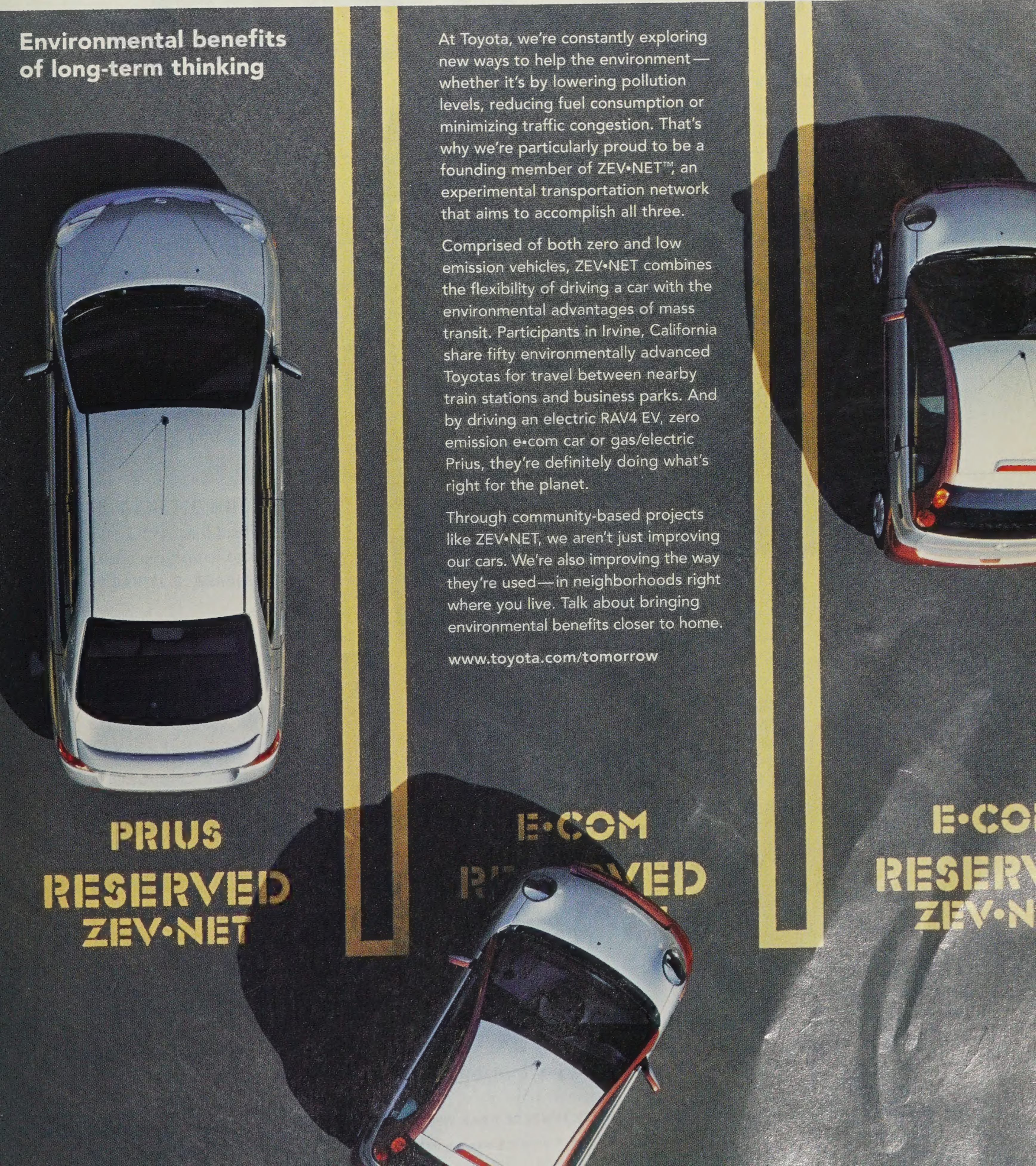


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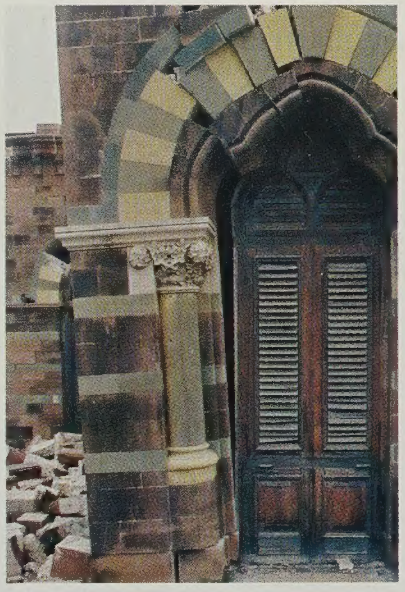
FEBRUARY 2003 VOLUME 112 NUMBER 1

FEATURES



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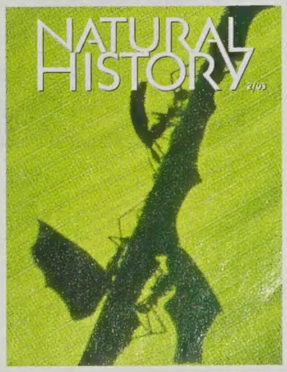
COVER
Leaf cutter ants (Atta colombica) *cultivate and protect a fungus, which they eat.*

PHOTOGRAPH BY CHRISTIAN ZIEGLER

STORY BEGINS ON PAGE 50



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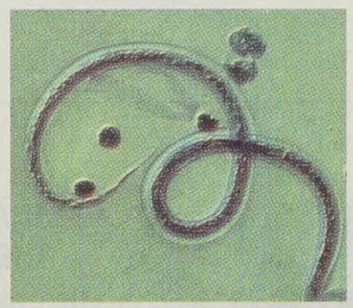
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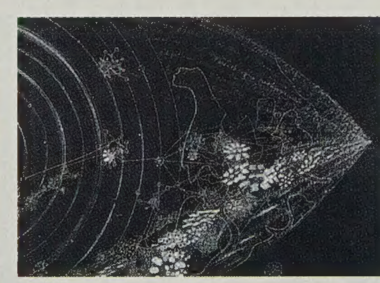
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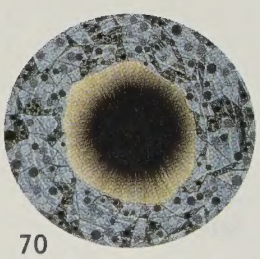
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New Engines of Evolution

Last month I noted that part of what many people don't like about science stems from its conclusion that we human beings don't occupy the center of the universe. But another great source of discomfort about science is its insistence that change is a pervasive feature of the world. Evolutionary change, of course, has long been a thorn in the side of many conservative Christians. Change in the heavens, the very model of permanence and order, seems to fly in the face of common sense. Maybe it's fortunate that our resistance to change is balanced by the fact that one human lifetime is too short for anyone to notice many of the grandest changes in nature. Yet the capacity of science to take the long view, to study events that take far more than a lifetime to unfold, often makes science the bearer of unwelcome tidings that undermine our yearning for stability.

Take evolution. One consequence of Darwinian evolution by natural selection is that as the world changes, what lives and what dies can change as well. In this month's cover story, Christian Ziegler and Egbert Giles Leigh Jr. document the subtle but pervasive effects of one world-changing event—the construction of the Panama Canal—on the ecology and biodiversity of the Panamanian tropical forest (see "Biosphere III," page 50). Other changes with substantial effects on the world's genetic history—agricultural breeding, the transport of species from one region to another—are too slow to be perceived without specialized techniques. Daniel G. Bradley, in his "Genetic Hoofprints" (page 36), describes how the magic lantern of DNA analysis has shed some surprising light on the evolutionary history of cattle since their domestication 10,000 years ago.

But what about the mechanisms of evolutionary change? What gives rise to the changes that individuals present for testing by natural selection? For much of the history of Darwinism the answers have been genetic mixing through sexual reproduction and random genetic mutation. But random mutation has seemed to many the Achilles' heel of the theory: the known rates of random mutation have seemed inconsistent with the time available for the observed biodiversity on Earth to have evolved.

Now the scientific understanding of change itself is changing. In his "Invasion of the Gender Benders" (page 58) John H. Werren describes one way that microorganisms are playing a key role in evolutionary change. The microorganisms that Werren studies are parasitic bacteria that survive by changing the reproductive process in their hosts. Some of these bacteria change their male hosts into females. Some kill all their hosts that happen to be male. Some make their hosts parthenogenetic, rendering the need for sexual reproduction irrelevant. Bacteria with such diabolical talents are not confined to some small and obscure corner of nature. They affect at least a fifth of all insect species, and perhaps as many as 70 percent. And their activities have broad implications for humanity. In a companion piece to Werren's article, T.V. Rajan eloquently recounts how microbiologists discovered that some of the same bacteria play a role in several of the most devastating pestilences that afflict humankind: elephantiasis and river blindness (see "The Worm and the Parasite," page 32).

The lesson of Werren's story is an apt one for our times (with apologies to Geoff Mack): "Change is everywhere, man."

—Peter Brown

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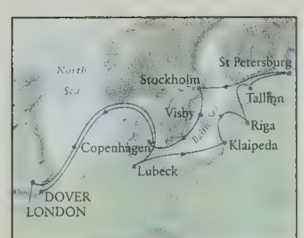

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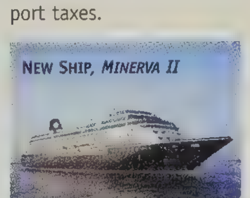

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SEA BIRD

THE NATURAL MOMENT

Raw Bar

Photograph by **Howie Garber**

THE NATURAL MOMENT

◄ *See preceding pages*

As their Latin name, *Ursus maritimus,* indicates, polar bears are true seafarers: they spend most of their lives aboard ships of shifting pack ice, patrolling for stowaway seals. In winter, ice floes bring bears to the edge of Alaska's northern coast, where the creatures may come ashore briefly. By early summer they head north again, sticking close to their melting, mobile hunting ground.

Occasionally, though, a bear misses the boat. The sow pictured here with her two cubs was one of fifty-five polar bears that failed to follow the shrinking ice this past September and ended up on Barter Island—the largest island in the Arctic National Wildlife Refuge.

Photographer Howie Garber was careful not to disturb the protective mother as she breakfasted with her cubs at the edge of the Inupiat village of Kaktovic. The three bears had been tearing into remnants of a bowhead whale, recently caught by the villagers on an authorized hunt. The whale carcass is visible in the background.

Females with dependent young, eager for a reliable food source, may be the most common visitors to such whale carcasses. But no one knows whether cubs fed onshore will master the lessons they'll need once they return to the ice.

—*Erin Espelie*

LETTERS

A Matter of Gravity

In his "Universe" column ["Going Ballistic," November 2002], Neil deGrasse Tyson eloquently covered many different and interesting aspects of "free fall." Of particular interest to me was his discussion of the chaotic motion of the planetary orbits and of the slingshot effect that can give spacecraft a planetary boost. (The motion of an object is chaotic if at each moment it can move in infinitely many possible directions, resulting in an erratic path. Think of the motion of a leaf blown about by the wind, or a drunk trying to walk a straight line.)

The chaos of planetary orbits is extremely subtle, and it takes careful measurement to notice it. But if a space probe passes a body such as the Moon in such a way that the probe is almost captured by the body's gravitational pull, the probe will usually linger for a few hours in the vicinity of the larger body, moving in a complicated, chaotic fashion before leaving abruptly on another path that is difficult to predict. The effect is called weak ballistic capture.

In 1990, I designed a new kind of route to the Moon for the Japanese spacecraft *Hiten,* requiring three months instead of the usual three days for the spacecraft to make the trip and leading to weak ballastic capture. The resultant chaotic motion offered a lot of flexibility to mission planning.

Permanent capture could be achieved using almost no fuel, an attractive option because *Hiten* carried so little. A more complicated plan was successfully followed, however: the craft stayed in weak capture for a few hours, then moved away from the Moon for six months to explore the Earth-Moon system, and finally returned to the Moon for placement in permanent capture. It turns out that weak capture is a slow version of the slingshot effect; recently weak capture was mathematically proved to be truly chaotic.

Edward Belbruno
Princeton University
Princeton, New Jersey

The figure-eight orbit that Neil Tyson mentions, as well as other newly discovered solutions to the old three-body problem, are so elegant that a name has been coined for them: choreographies. The figure eight is only the simplest example; other orbits are wildly more complex, with shapes that look more like fluttering butterflies. And those three-body orbits have been quickly generalized to even more fascinating dances for four or more bodies. Animated examples can be viewed on the Web at www.ams.org/new-in-math/cover/orbits1.html.

As a theoretical astrophysicist working in stellar dynamics, I am sobered by the fact that great mathematicians and physicists worked on the three-body problem over the past three centuries without having any idea that orbits of this kind were awaiting discovery. And who knows what else there is to be found. It is not only with telescopes that new astronomical objects can be discovered. With even a small personal computer, a lucky guess, and enough persistence, anybody is now in a position to find new solutions to age-old problems of a kind that were completely beyond what Newton and the Le's and La's of celestial mechanics (Leverrier, Legendre, Lagrange, and Laplace, to name a few) could handle.

Piet Hut
Institute for Advanced Study
Princeton, New Jersey

Neil Tyson's article brought to mind my own attempt to dig a hole from Oklahoma to China. I was seven or eight at the time and asked my dad if I could dig down behind the house. "Sure, honey," he replied, barely looking up from the paper. The project was called off several weeks later when his tractor nearly fell into the hole. I was terribly disappointed, but now I have learned that a major catastrophe was averted.

First of all I would have been vaporized by the fierce heat of the iron core. At best I would have popped out in the southern Indian Ocean, which would have been dangerous because I couldn't swim. At least it is a relief to know the ocean water pouring into the tunnel

would have surged back and forth, rather than flooding the Midwest.
Gloria Jones-Wolf
Elk Falls, Kansas

The Shark Has Sharp Turns

In his "Biomechanics" column on the hammerhead shark ["Head Turner," November 2002], Adam Summers reports that the shark does not bank its winglike head as it turns. He thus dismisses the idea that the head provides lift and maneuverability, as does the wing of an aircraft. But sharks are different from aircraft in two important respects (apart from the obvious ones).

First, water provides sharks with substantial buoyancy, whereas air does not confer the same benefit to aircraft. Second, a shark can make a yawing (sideways) turn without banking, simply by bending its body and adjusting vertically oriented fins to keep from sinking. Airplanes turn while remaining aloft primarily by controlling the positions of ailerons mounted on horizontally oriented wings.

Nevertheless, the shark's head may help the animal maneuver—if not in making sideways turns, then at least in pitching it up or down. In that respect, the forward position of the large head is optimal, though further analysis is needed to confirm any such hydrodynamic function.
Frank E. Fish
West Chester University
West Chester, Pennsylvania

Wings and Stings

In his tale of initiation into the pleasures and perils of rainforest field research ["Bites of Passage," October 2002], Nathan Welton writes that the "mad scientists" of La Selva Biological Station, in Costa Rica, "happily spend their days plucking the wings off aerial insects and crucifying them on Styrofoam boards." As thirty-year veterans of research at La Selva and co-directors of the ongoing Arthropods of La Selva (ALAS) project—an effort to make an inventory of all the major groups of insects, spiders, and mites at the station—we don't mind being tagged in good fun as "mad scientists."

But there is no humor in the cruel image of crucifixion, which implies the intentional imposition of an agonizing death. Ethical entomologists, certainly including all who work at La Selva, use the most humane methods available to kill arthropods (freezing or fast-acting chemicals) before mounting them as study specimens. We take lives, however small, only when there is a legitimate scientific reason to do so, and nobody we know plucks wings off insects.
Robert K. Colwell
University of Connecticut
Storrs, Connecticut

John T. Longino
The Evergreen State College
Olympia, Washington

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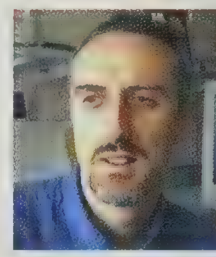
CONTRIBUTORS

Howie Garber ("The Natural Moment," page 10) practices emergency room medicine in Salt Lake City, Utah, but he finds wildlife photography "as challenging and exciting" as his day job. Garber has received numerous prizes, including the 1997 BG Wildlife Photographer of the Year in the "Landscape (Wild Places)" category. A 500-millimeter lens enabled him to photograph a mother polar bear and her two cubs from a reasonably safe distance. More of Garber's photographs are on view at www.wanderlustimages.com.



"Cattle is in the blood," is the way **Daniel G. Bradley** ("Genetic Hoofprints," page 36) describes himself. A lecturer in genetics and a fellow at Trinity College, Dublin, Bradley grew up on a small farm in northern Ireland and recalls tending cattle on spring mornings before going to school. Even today not all his work is done in the lab. To help trace the origins of African cattle, he has traveled several times to western Africa and, with help from the U.N. Food and Agriculture Organization, he has visited remote pastoral villages in Guinea and Guinea-Bissau. He once drove through a desert strewn with spent rocket shells to reach an area of Chad that is home to huge-horned African Kuri cattle.

On January 26, 2001, when a magnitude 7.6 earthquake struck the Indian state of Gujarat, **Susan Hough** ("Shaken to the Core," page 42) immediately began to search the Internet for first-person accounts of the event. She knew the Indian quake would be invaluable for calibrating the intensity of a series of mid-continental earthquakes that shook southeastern Missouri nearly two centuries ago. Hough is a geophysicist at the U.S. Geological Survey in Pasadena, California, and the author of the book *Earthshaking Science: What We Know (and Don't Know) about Earthquakes.* **Roger Bilham** is a professor of geology at the University of Colorado in Boulder and an associate director of the Cooperative Institute for Research in Environmental Sciences. In the past three decades he has done extensive geodetic surveying in India and Tibet and completed numerous investigations of historic Indian earthquakes. He is the author of more than 130 articles on earthquake-related processes.

Christian Ziegler and **Egbert Giles Leigh Jr.** ("Biosphere III," page 50) teamed up in Panama to document the way animals and plants have adapted to life on a small island in a tropical forest. The result is their book *A Magic Web: The Tropical Forest of Barro Colorado Island* (published last month by Oxford University Press; see www.amagicweb.com). Based in Vancouver and Panama, Ziegler *(left)* is a wildlife and nature photographer and writer with a background in biology. His work has appeared in magazines throughout the world, and in 2001 he won a prize in the BG Wildlife Photographer of the Year Competition. Leigh *(right)* is a tropical ecologist with thirty years' experience on Barro Colorado as a staff scientist for the Smithsonian Tropical Research Institute.

When **John H. Werren** ("Invasion of the Gender Benders," page 58) began his graduate studies in biology at the University of Utah, he focused on behavioral ecology, investigating how and why parasitic wasps manipulate the proportion of males and females in their progeny. But he found that there were also "genetic parasites" that altered the sex ratio. Some of the parasites turned out to be microorganisms. After completing his Ph.D., he entered the U.S. Army, and, as he describes it, "in one of those funny coincidences, the Army decided that I would work on water bacteriology, despite my having no formal training in bacteriology. So I learned a lot of bacteriology and, in collaboration with a colleague back in Utah, found a male-killing microbe in the parasitic wasps." Now a professor of biology at the University of Rochester in New York, Werren studies *Wolbachia* bacteria and their role in the evolution of new insect species.

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By Stéphan Reebs

Bill Scanga, *Living Room (Tom & Jerry)*, 1997

HEEDLESS YOUTH Sometimes teenagers seem drawn to risky behavior like moths to porch lights. But among adolescent mammals, they're not alone. Novelty-seeking—the urge to explore unknown environments—seems to surface at this stage of development. Perhaps the behavior is related to the need to seek one's fortune, or at least living space and reproductive partners, outside one's natal group.

To check for teenage recklessness in a small mammal, Simone Macrì and her colleagues at the Italian National Institute of Health in Rome placed mice of varying ages, one at a time, in the center of an elevated structure with four narrow passageways that led radially outward. Two passageways were enclosed by transparent protective walls; two were bounded only by slightly raised edges, thereby offering less protection against tumbles. Each mouse wandered wherever it wanted for several minutes while the biologists watched.

The adolescent mice made some 80 percent more entries into the unprotected passageways—and entered them with less hesitation—than did the preadolescents or the adults. Yet all the mice spent about the same amount of time exhibiting a body posture that typically indicates anxiety and risk assessment. Interpretation? The adolescent mice were aware of the dangers associated with the open-sided passageways, but adopted a devil-may-care attitude nonetheless. (And they don't spend much time watching TV at home with the family.) ("Risk taking during exploration of a plus-maze is greater in adolescent than in juvenile or adult mice," *Animal Behaviour* **64:**541–46, October 2002)

GRAIN GAIN Nearly every day, more than half the people on Earth eat rice, a dietary staple grown mostly in flooded fields. Unfortunately, the roots of rice plants are a source of nutrients for microorganisms that, under the anaerobic conditions prevailing in flooded ground, generate substantial amounts of methane gas. After carbon dioxide, methane is the second most damaging greenhouse gas in the atmosphere.

Not only is more methane released in the rainy season than in the dry season, as one would expect, but greater amounts of methane come from rice paddies with lower-than-average yields of grain. A team of Dutch and Filipino biologists, led by Hugo Denier van der Gon of Wageningen University in the Netherlands, thought they knew why. The level of methane production, they suggested, could depend on how much carbon is available to the microorganisms once the plant has used up whatever carbon it needs to make its grains of rice. During the wet season, as well as in unproductive fields, each plant makes fewer grains, so more carbon could be making its way to the microorganisms near the roots, and more methane would be produced.

The biologists tested their idea by removing part of the stems where the rice grains develop; as predicted, the larger the segment removed, the more methane was released. And when they boosted photosynthesis—and therefore carbon production—by adding nitrogen, even more methane was given off. The investigators also noted an ancillary advantage, implied by their findings, of developing new rice varieties able to bear more grains per unit biomass: more food per plant goes hand in hand with less greenhouse methane. ("Optimizing grain yields reduces CH_4 emissions from rice paddy fields," *Proceedings of the National Academy of Sciences* **99:**12021–24, September 17, 2002)

Rice fields, Assam, India

EXPERIMENT OF THE MONTH When marine biologist Scott A. Eckert first tracked the deepwater dives of leatherback sea turtles in the Caribbean, his data told him the animals were spending middays at or just below the surface. He presumed they were basking in the sunshine, as reptiles often do. Eckert, who is a member of the scientific staff at the Hubbs Sea World Research Institute in San Diego, had attached depth recorders to the turtles' shells, but the instruments were naturally silent about the turtles' horizontal movements. Not entirely satisfied with his assumptions, he decided to verify them.

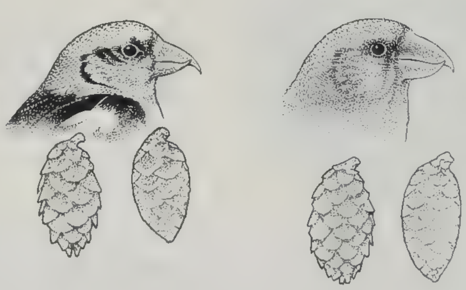
Leatherbacks dwell primarily in the open ocean, but in their breeding years the females drag themselves onto beaches fairly regularly to lay their eggs. When seven females came ashore to nest on Saint Croix, Eckert fitted each one with a harness that included a custom-built marine speedometer. At sea, if a turtle surfaced to soak up the rays, the speedometer would pop out of the water, the recording device would pause, and the logged speed would drop to zero. (In earlier attempts to measure swim speeds, boats followed the turtles, a technique that some biologists suspected could have altered the turtles' behavior.)

Ten days later, when the turtles returned to their onshore nests, Eckert retrieved the data loggers. Contrary to his expectations, they showed that the leatherbacks never loafed: they swam almost constantly, day and night, at about a mile and a half an hour. At night they often dived for jellyfish, but in the middle of the day they glided horizontally about six feet underwater—deep enough to avoid the push and pull of the waves, yet shallow enough to perhaps orient themselves to the sun as they traveled between foraging sites. ("Swim speed and movement patterns of gravid leatherback sea turtles [*Dermochelys coriacea*] at Saint Croix, U.S. Virgin Islands," *Journal of Experimental Biology* **205:**3689–97, December 1, 2002)

Leatherback sea turtle, sans harness

THREE'S A CROWD Crossbills and squirrels both feed on the seeds of conifer cones—a dietary triangle that sets the stage for intriguing evolutionary interactions. In the Rocky Mountains, red squirrels harvest most of the cones of lodgepole pines before red crossbills can get at them. According to Craig W. Benkman, a biologist at New Mexico State University (NMSU) in Las Cruces, the cones in the Rockies have few seeds and are relatively wide—evolutionary adaptations that make them less desirable to squirrels. But in areas where squirrels are absent, the cones have focused their defenses on the threat posed by crossbills. The shape of the cones is different, and the scales are thicker—traits that resist the crossbills' attempts to remove the seeds. In turn, the crossbills in the squirrel-less areas have evolved deeper bills, thereby partly countering the cones' defenses.

Now Benkman and Thomas L. Parchman, also at NMSU, have found a similar case of coevolution on the other side of the continent. Squirrels didn't live in Newfoundland until they were introduced there in 1963—too recently for conifers to have evolved in response to the change. Accordingly, the cones of Newfoundland's main conifer, the black spruce, had focused on the threat of the native red crossbill. These cones are larger, with thicker scales than the cones of the tree's counterparts on the mainland, where squirrels have long resided. Fittingly, Newfoundland's crossbills had unusually deep bills.



Crossbills and black spruce cones from the eastern Canadian mainland (left) and Newfoundland (right)

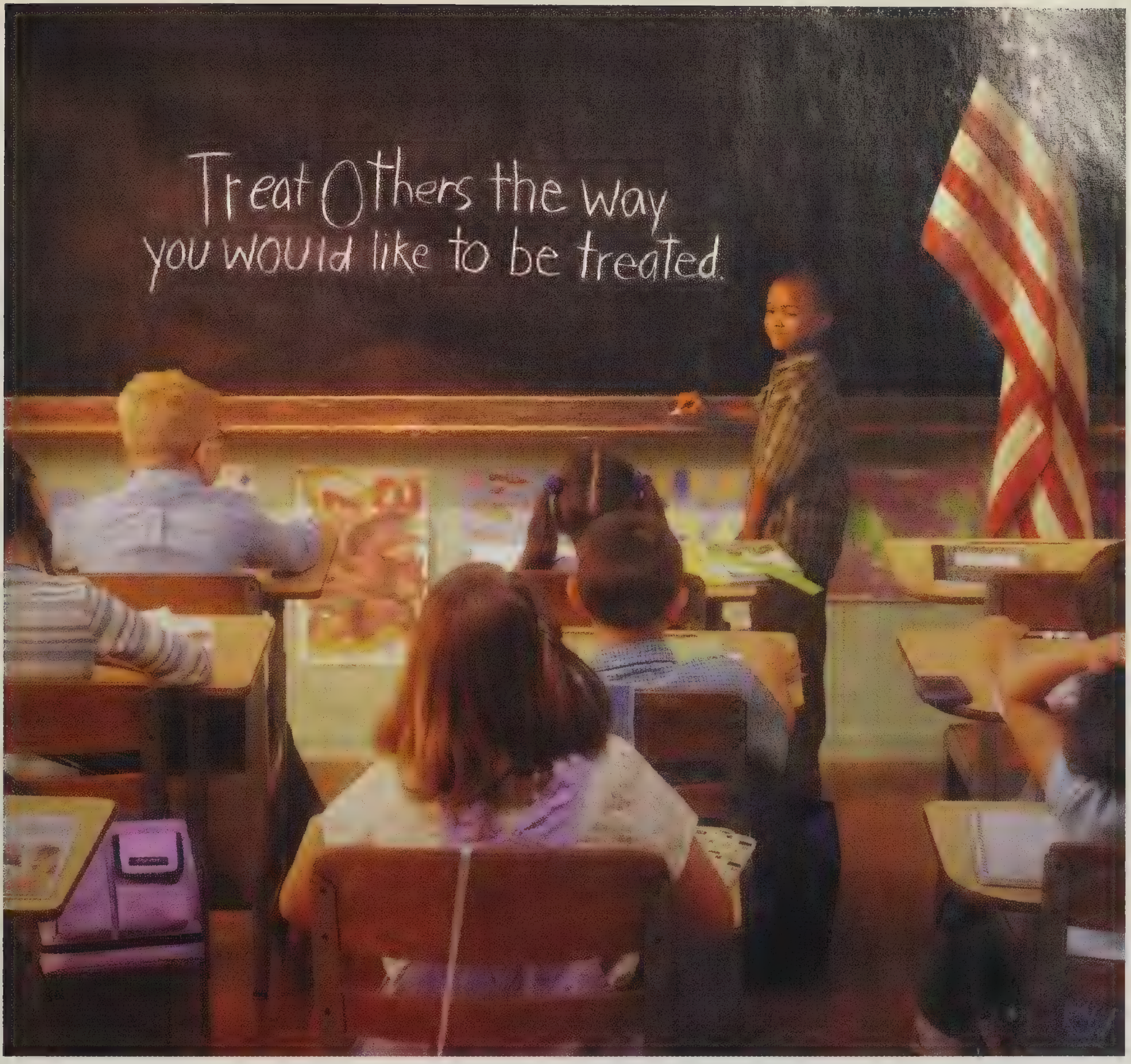
Unfortunately, Parchman and Benkman had to find museum specimens to measure the bill size of Newfoundland's red crossbills. Once the squirrels arrived in Newfoundland in 1963, the local crossbills became rare, if not extinct. Because the black spruce cones were defenseless against the squirrels, the biologists reasoned, the squirrels probably grabbed so many of them that the local crossbills soon had nothing left to eat. ("Diversifying coevolution between crossbills and black spruce on Newfoundland," *Evolution* **56:**1663–72, August 2002)

LETTING GO To escape a predator's grasp, some prey would rather give up a limb than give up on life. Through a process called autotomy, muscles can contract violently along the base of an appendage, breaking off the limb. Thus can sea stars cast off an arm, and various reptiles shed their tails.

Kerstin Wasson, a biologist at the Elkhorn Slough National Estuarine Research Reserve in Watsonville, California, and her colleagues decided to quantify the benefits of autotomy. They put *Petrolisthes* porcelain crabs in the company of larger, predatory crabs and waited until a predator grabbed a porcelain by the claw. Two-thirds of the porcelains jettisoned the claw and escaped alive as the predator munched the detached hors d'oeuvre. The other third fought back, but most of them ended up as a full entrée.

Porcelains have large claws for their body size. Such claws may divert a predator's attention away from the main part of the porcelain's body, Wasson and her colleagues suggest, and keep the predator safely busy for a time. ("Hair-trigger autotomy in porcelain crabs is a highly effective escape strategy," *Behavioral Ecology* **13:**481–86, July 2002)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*



Treat Others the way
you would like to be treated.

Aristotle teaching astronomers, Seljuq dynasty, Turkey, early 13th century

Naming Rights

How to stake a claim in the dictionary of science

By Neil deGrasse Tyson

If you visit the gift shop at the Hayden Planetarium in New York City, you'll find all manner of space-related paraphernalia for sale. Familiar things are in stock—plastic models of the Space Shuttle and the International Space Station, cosmic refrigerator magnets, Fisher space pens. But there are unusual things, too—astronomy Monopoly, Saturn-shaped salt-and-pepper shakers, dehydrated ice cream of the kind originally confected for astronauts. And that's not to mention the weird things, such as Hubble Telescope pencil erasers, Mars rock super-balls, and edible space worms. You'd expect a place like the planetarium to stock such stuff. But something much deeper is going on. The gift shop's offerings bear silent witness to a half century of American scientific discovery.

In the twentieth century, astronomers in the United States discovered galaxies, the expansion of the universe, the nature of supernovas, quasars, black holes, gamma ray bursts, the origin of the elements, the cosmic microwave background, and most of the known planets in orbit around solar systems other than our own. Although the Russians reached one or two places first, the U.S. sent space probes to Mercury, Venus, Jupiter, Saturn, Uranus, and Neptune. U.S. probes have also landed on Mars and on the asteroid Eros. U.S. astronauts have walked on the Moon. And nowadays most Americans take all this for granted, which is practically a working definition of culture: something everyone does or knows about, but no longer actively notices.

While shopping at the supermarket, most Americans aren't surprised to find an entire aisle filled with sugar-loaded, ready-to-eat breakfast cereals. But foreigners notice this kind of thing immediately, just as traveling Americans immediately notice that supermarkets in Italy have vast selections of pasta, and that markets in China and Japan offer astonishing choices of rice. Part of the great pleasure of foreign travel comes from the flip side of not noticing your own culture while you're surrounded by it: you realize what you hadn't noticed about your own country, and you notice what people in other countries don't realize about themselves.

Snobby people from other countries like to make fun of the U.S. for its abbreviated history and its uncouth culture, particularly compared with the millennial legacies of Europe, Africa, and Asia. But a few hundred years from now historians will surely see the twentieth century as the American century—the one in which American discoveries in science and technology rank high among the world's list of treasured achievements.

Obviously the U.S. has not always sat atop the ladder of science. And there's no guarantee or even likelihood that American preeminence will continue. As the capitals of science and technology shift from one nation to another, rising in one era and falling in the next, each culture leaves its imprint on the continuing attempt of our species to understand the universe and our place in it.

Many factors influence how and why a nation will make its mark at a particular time in history. Strong leadership matters. So does access to resources. But something else must be present—something less tangible, but with the power to drive people to focus their emotional, cultural, and intellectual capital on creating islands

of excellence in the world. On the blind assumption that things will continue forever as they are, people who live in such dynamic times often take the excellence for granted, leaving the nation's achievements susceptible to abandonment by the very forces that gave rise to them.

Beginning in the 700s and continuing for nearly 400 years—while Europe's Christian zealots were disemboweling heretics—the Abbasid caliphs created a thriving intellectual center of arts, sciences, and medicine for the Islamic world in the city of Baghdad. Muslim astronomers and mathematicians built observatories, designed advanced timekeeping tools, and developed new methods of mathematical analysis and computation. They preserved extant works of science from ancient Greece and translated them into Arabic. They collaborated with Christian and Jewish scholars. Baghdad became a center of enlightenment. Arabic was, for a time, the lingua franca of science.

The influence of these early Islamic contributions to science remains to this day. For example, so widely distributed was the Arabic translation of Ptolemy's magnum opus on the geocentric universe (originally written in Greek in A.D. 150) that even today, in all translations, the work is known by its Arabic title, *Almagest*, or "The Greatest."

For a time, Arabic was the lingua franca of science, and Baghdad its capital.

The Iraqi mathematician and astronomer Muhammad ibn Musa al-Khwarizmi gave us the words "algorithm" (from his name, al-Khwarizmi) and "algebra" (from the word *al-jabr* in the title of his book on algebraic calculation). And the world's shared system of numerals—0, 1, 2, 3, 4, 5, 6, 7, 8, 9—though Hindi in origin, was neither common nor widespread until Muslim mathematicians exploited it. Furthermore, the Muslims made full and innovative use of the zero, which did not exist among Roman numerals or in any established numeric system. Today, with legitimate reason, the ten symbols are internationally referred to as Arabic numerals.

Portable brass astrolabes were also developed in the Islamic world. Derived from ancient prototypes, they became as much works of art as tools of astronomy. An astrolabe projects the domed heavens onto a flat surface; with its layers of rotating and non-rotating dials, it resembles the busy, ornate face of a grandfather clock. The astrolabe enabled people to measure the positions of the Moon and the stars on the sky, from which they could deduce the time—a useful thing to know, particularly if it's time to pray. The device was so influential as a terrestrial connection to the cosmos that, to this day, nearly two-thirds of the brightest stars in the night sky retain their Arabic names.

The star names typically translate into an anatomical part of the constellation being described. Famous ones on the list (along with their loose translations) include Rigel (*Ar-Rijl*, "foot") and Betelgeuse (*Yad al-Jauza*, "hand of the central one"), the two brightest stars in the constellation Orion; Altair (*At-Ta'ir*, "the flying eagle"), the brightest star in the constellation Aquila; and the variable star Algol (*Al-Ghul*, "the demon"), the second brightest star in the constellation Perseus (the star's name refers to the blinking eye of the bloody severed head of Medusa held aloft by Perseus). In the less-famous category are the two brightest stars of the constellation Libra, though in the heyday of the astrolabe they were identified with the scorpion: Zubenelgenubi (*Az-Zuban al-Janubi*, "southern claw") and Zubenesch-

amali (*Az-Zuban ash-Shamali*, "northern claw"), currently the longest star names in the sky.

At no time since the eleventh century has the Islamic world regained the scientific influence it enjoyed during the preceding four centuries. The late Pakistani physicist Abdus Salam, the first Muslim ever to win the Nobel Prize, lamented:

> There is no question, but [that] today, of all civilizations on this planet, science is the weakest in the lands of Islam. The dangers of this weakness cannot be overemphasized since honorable survival of a society depends directly on strength in science and technology in the conditions of the present age.

Plenty of other nations have enjoyed periods of scientific fertility. Think of Great Britain and the basis of Earth's system of longitude. The prime meridian is the line that separates geographic east from west on the globe. Defined as zero degrees longitude, it bisects the base of a telescope at an observatory in Greenwich, a London borough on the south bank of the River Thames. The line doesn't pass through New York City, or Moscow, or Beijing. Greenwich was chosen in 1884 by an international consortium of longitude mavens who met in Washington, D.C., for that very purpose.

By the late nineteenth century, astronomers at the Royal Observatory Greenwich—founded in 1675 and based, of course, in Greenwich—had accumulated and catalogued a century's worth of data on the exact positions of thousands of stars. Today we calibrate our watches with atomic clocks, but back then there was no timepiece more reliable than the rotating Earth itself. And there was no better record of the rotating Earth than the stars that passed slowly overhead. And nobody measured the positions of passing stars better than the astronomers at the Royal Observatory Greenwich.

Until the mid-eighteenth century, Great Britain lost many ships at sea

because captains would not know where on Earth they were: the means to determine their longitude with precision did not yet exist. One particularly tragic disaster took place in 1707, when the British fleet, under Admiral Sir Clowdisley Shovell, ran aground into the Scilly Isles, west of Cornwall, losing four ships and 2,000 men. That was finally enough. The British Parliament commissioned a Board of Longitude and offered a fat cash award—£20,000—to the first person who could design an ocean-worthy chronometer. The timepiece was destined to be important in both military and commercial ventures. When synchronized with the time at Greenwich, such a chronometer would determine a ship's longitude within half a degree. The captain could just subtract the local time (readily obtained from the observed position of the Sun or stars) from the chronometer's time, and the difference between the two would be a direct measure of his ship's longitude east or west of the prime meridian.

In 1735 Parliament's challenge was met by an English clockmaker, John Harrison. Three decades later, he produced his fourth and final version—an almost palm-size item, less than five inches in diameter. As valuable to the navigator as is a live person standing watch at a ship's bow, Harrison's chronometer gave renewed meaning to the word "watch."

Because of Britain's sustained support for achievements in astronomical and navigational measurement, the Royal Observatory Greenwich landed the prime meridian. This decree fortuitously placed the international date line (180 degrees away from the prime meridian) in the middle of nowhere, on the other side of the globe in the Pacific Ocean. No country would be split into two days, leaving it beside itself on the calendar.

If the English have forever left their mark on the spatial coordinates of the world, the world's system of temporal coordinates—a Sun-based calendar—is the product of an investment in science within the Roman Catholic Church. The incentive was practical: the need to keep the date for Easter in the early spring. So important was this need that Pope Gregory XIII established the Vatican Observatory, staffing it with erudite Jesuit priests who tracked and measured the passage of time with unprecedented accuracy. By decree, the date for Easter had been set to the first Sunday after the first full Moon after the vernal equinox (thereby preventing Maundy Thursday, Good Friday, and Easter Sunday from ever falling on a special day in some-

An astrolabe of Moorish design, c. 1300

body else's lunar-based calendar). That rule works as long as the first day of spring stays where it belongs, on March 21. But the Julian calendar of Julius Caesar's Rome was sufficiently inaccurate that by the sixteenth century it had accumulated ten extra days, placing the first day of spring on March 11. The quadrennial leap day, a principal feature of the original Julian calendar, had slowly overcorrected the time, pushing Easter earlier and earlier in the year.

In 1582, when all the studies and analyses were complete, Pope Gregory deleted the offending ten days from the calendar, declaring the day after October 4 to be October 15. The Church also initiated a further adjustment: omitting the leap day every century year that is not evenly divisible by 400, thus correcting for the Julian calendar's overcorrecting leap day itself.

This new "Gregorian calendar" was further refined in the twentieth century to become even more precise, preserving the accuracy of your wall calendar for tens of thousands of years to come. Nobody else had ever kept time with such precision. Enemy states of the Catholic Church (such as Protestant England and its rebellious progeny, the American colonies) were slow to adopt the change, but eventually everyone in the modern world, including cultures that have traditionally relied on Moon-based calendars, has adopted the Gregorian calendar as the standard for international business, finance, and politics.

Ever since the onset of the Industrial Revolution, European contributions to science and technology have become so embedded in Western culture that it may now take a special effort to notice them at all. The Industrial Revolution was a breakthrough in our understanding of energy, enabling engineers to dream up ways to convert it from one form to another. In the end, the revolution would replace human power with machine power, drastically enhancing the productivity of nations and the subsequent distribution of wealth around the world.

The language of energy is rich with the names of scientists who contributed to the effort. James Watt, the Scots inventor who perfected the steam engine in 1765, has the moniker best known outside the circles of engineering and science. Either his last name or its initial gets stamped on the top of practically every lightbulb. A bulb's wattage measures the rate of its energy consumption, which correlates with its brightness. Watt made his famous contribution while repairing a steam engine at the University of Glasgow, which was, at the time, one of the

world's most fertile centers for engineering innovation.

The English physicist Michael Faraday discovered electromagnetic induction in 1831, which enabled him to construct the first electric motor. The farad, a measure of a device's capacity to store electric charge, probably doesn't do full justice to his contributions to science.

The German physicist Heinrich Hertz discovered electromagnetic waves in 1888, opening the door to communication via radio; his name survives as the unit of frequency, along with its metric derivatives: kilohertz, megahertz, and gigahertz.

From the Italian physicist Alessandro Volta we have the volt, a unit of electric potential. From the French physicist André-Marie Ampère we have the unit of electric current known as the ampere, or "amp" for short. From the British physicist James Prescott Joule we have the joule, a unit of energy. The list goes on and on.

With the exception of Benjamin Franklin and his tireless experiments with electricity, the U.S. as a nation watched this chapter of human achievement from afar, preoccupied with gaining independence from Britain and exploiting the economies of slave labor.

In the late eighteenth century the Industrial Revolution was in full swing, but so too was the French Revolution. The French used the occasion to shake up more than the royalty; they also introduced the metric system to standardize what was then a world of mismatched measures—confounding science and commerce alike. Members of the French Academy of Sciences led the world in measuring the Earth's shape, proudly determining it to be an oblate spheroid. Building on that knowledge, they defined the meter to be one ten-millionth the distance along the Earth's surface from the North Pole to the equator, passing through—where else?—Paris. This measure of length was standardized as the separation between two marks etched on a special bar of platinum alloyed with iridium. The French devised other decimal standards as well; most have been adopted by all the nations of the world except Liberia, Myanmar, and the U.S. The original artifacts of the metric system are preserved at the International Bureau of Weights and Measures—located, of course, near Paris.

Beginning in the late 1930s the U.S. became a nexus of activity in nuclear physics. Much of the intellectual capital came from the exodus of scientists from Nazi Germany. But the financial capital came from Washington, earmarked for the race against Hitler to build an atomic bomb. The coordinated effort to produce the bomb was known as the Manhattan Project, so named because much of the early research had been done in Manhattan, at Columbia University.

The wartime investments had huge peacetime benefits for the community of nuclear physicists. From the 1930s through the 1980s, American accelerators were the largest and most productive in the world. These racetracks of physics act as windows into the fundamental structure and dynamics of matter. They create beams of subatomic particles, accelerate them to near the speed of light with a cleverly configured electric field, and smash them into other particles, busting them to smithereens. Sorting through the smithereens, physicists have found evidence for hordes of new particles and even for new laws of physics.

American nuclear physics laboratories are duly famous. Even people who are physics-challenged will recognize the top names: Brookhaven, Fermilab, Lawrence Berkeley, Lawrence Livermore, Los Alamos, Oak Ridge. Physicists at the labs discovered new particles, isolated new elements, informed a nascent theoretical model of particle physics, and collected Nobel Prizes for doing so.

The American footprint in that era of physics is forever inscribed at the upper end of the periodic table: ele-

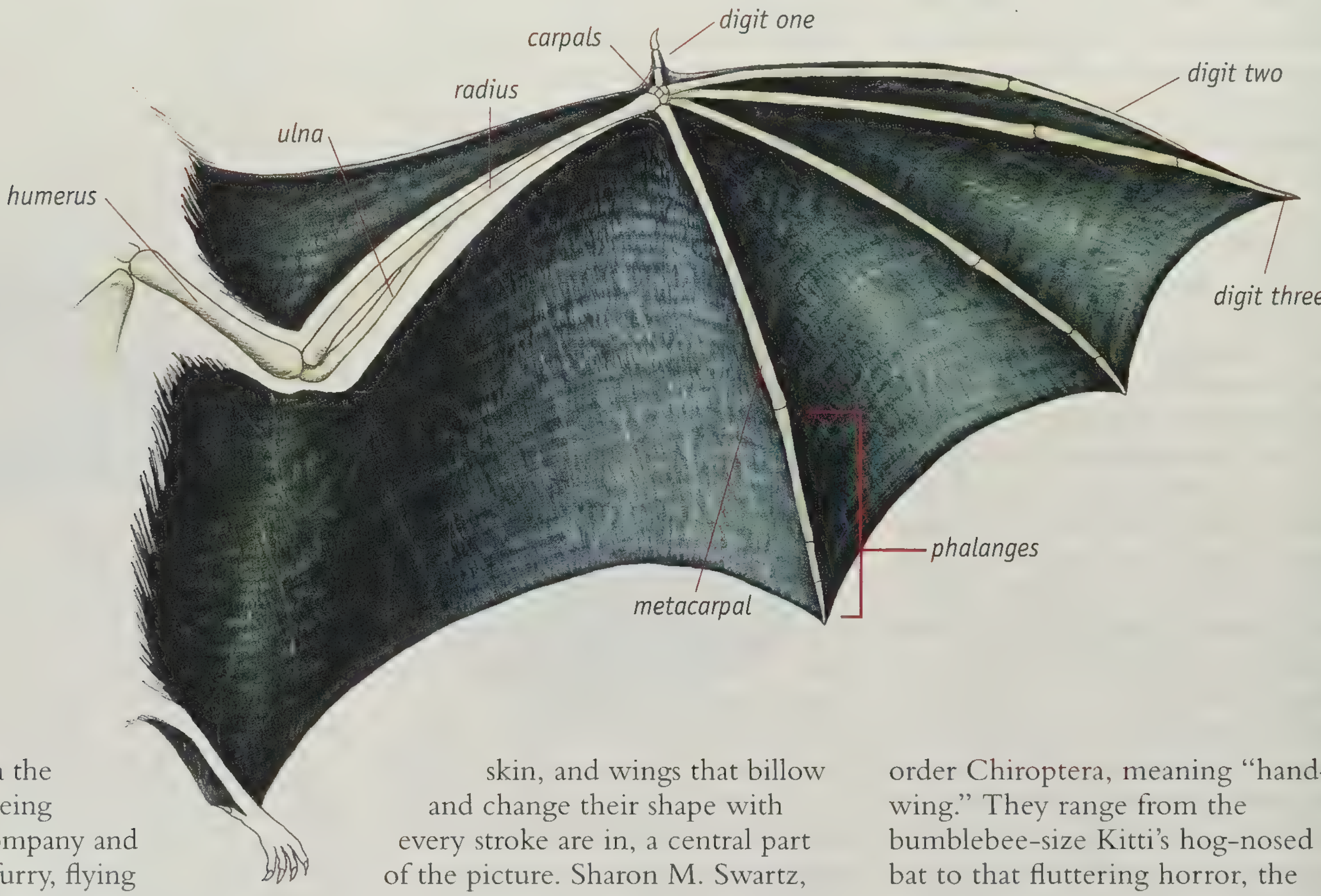
(Continued on page 74)

BIOMECHANICS

Flap Your Hands

To fly like a bat, you need flexible hand bones and stretchable skin across your fingers.

By Adam Summers ~ Illustrations by Shawn Gould



Both the Boeing Company and bats (the furry, flying mammals) are leaders in aeronautical performance and versatility, yet they have strikingly different approaches to getting (and staying) off the ground. The kind of flight most of us have experienced begins with a stiff, strong airfoil, one that undergoes few changes of shape in flight. Built out of aluminum alloys and carbon-fiber composites, rigid wings provide the steady airflow needed to generate lift that is orderly, predictable, and well understood.

Bat flight is an entirely different affair. Rigid, strong, and heavy are out. Thin, whippy bones, stretchy skin, and wings that billow and change their shape with every stroke are in, a central part of the picture. Sharon M. Swartz, a biologist at Brown University in Providence, Rhode Island, and her students Kristin L. Bishop and Maryem-Fama Ismael Aguirre are investigating the fluttering flight of bats with both hands-on tests and computer simulations. They are learning what works, and what doesn't, when fliers must contend with unsteady airflows and with airfoils that continuously deform.

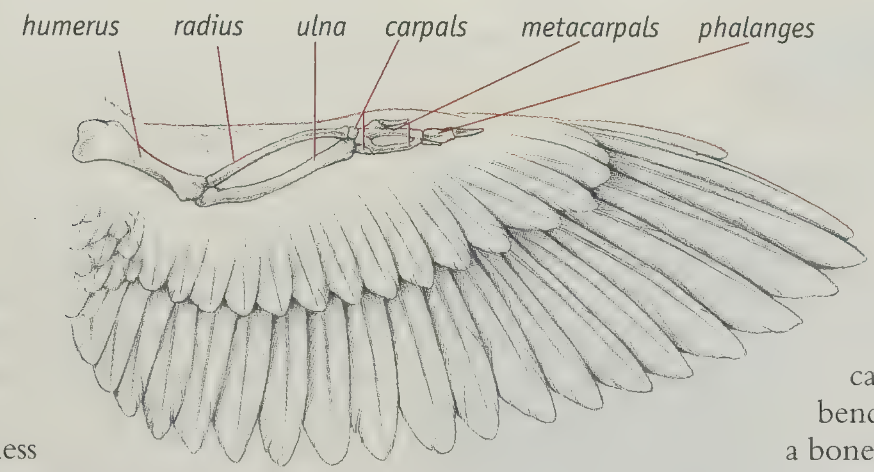
Nearly a quarter of all mammal species are bats, and they are the only winged animals in the class Mammalia. All bats belong to the order Chiroptera, meaning "hand-wing." They range from the bumblebee-size Kitti's hog-nosed bat to that fluttering horror, the vampire bat, to the Malayan flying fox, the largest species.

A bat's wings are not only different from a 747's; they are also quite unlike the wings of a bird. They lack feathers, obviously. And although the humerus, radius, and ulna of birds are quite similar to the humerus and radius of bats (which have only a vestigial ulna), avian hand bones have largely fused [*see illustration on opposite page*]. But bats' carpal bones conjoin at a point about halfway along the leading edge of the wing; the bones of the short, clawed first finger (homologous to our thumb) jut forward. The long second

finger forms most of the distal half of the wing's leading edge. The third finger runs closely behind the second, but all the way to the tip of the wing. The fourth and fifth fingers run from the leading edge to the trailing edge of the wing, and stretched across all the fingers is a thin, flexible skin [*see illustration on opposite page*].

Bones don't bend—at least that's the message we get after an orthopedist applies a cast to the results of a misjudgment. But the bones of a bat's fingers have adaptations that promote bending. The digits' cartilage lacks calcium toward the fingertips, making them less apt than ordinary bone is to splinter under stress. Also, the cross section of the finger bone is not circular, as is the bone in a human finger, but flattened. This shape further encourages flexion (think about how much easier it is to bend a soda straw if you first give it a squeeze to flatten the thing).

Imagine wanting, as Swartz did, to measure how much bat wing bones bend. It's not easy. When bats fly, their wings flail up and down in such a complex path that a three-dimensional reconstruction of the flight would be impossible, even from a movie. Swartz and her colleagues David Carrier of the University of Utah in Salt Lake City and Michael Bennett of the University of Queensland in Brisbane solved the problem about a decade ago by gluing minute metal-foil strain gauges directly to the bones of bats.



The bat they studied was the gray-headed flying fox *(Pteropus poliocephalus),* about the size of a small chihuahua and sporting a nearly four-foot wingspan. It's huge for a bat, but just barely large enough to support the scientists' gauges. In the initial study, Swartz and the others attached gauges to the humerus and radius of the flying foxes; in later work, Swartz attached them to the fingers, between both the first and second and the second and third knuckles (to the proximal and medial phalanges, as an anatomist would say). As the animals flew about inside a long, spacious cage, the bending of a bone would also flex the gauge, thereby changing the electrical resistance in the foil. The tests demonstrated that the wing bones, about the same length as a person's index finger, deformed three-quarters of an inch or more with every beat of the wing.

Swartz went on to develop a computer model of bone deformation during flapping flight. She found that not only are flexible bones vital for bat flight, but so too is the skin that covers the hand-wing. The skin of most mammals can stretch equally in every direction, but bat-wing skin has many times more give along the direction between its body and its wingtip than it does between the leading edge and the trailing one. And when the skin billows out as the bat flies, it is stiff enough to transmit substantial force along the length of the wing and generate lift. In fact, if the skin were any stiffer, the delicate finger bones, despite their flexibility, would probably break.

The computer models, taking into account bones, skin, and the usual motions of flight, suggest that there are some limits to being batty. For one thing, a fruit bat that flies home with a mango in its mouth is pushing the limits of its flight equipment. The model predicts that even though the stresses of unladen flight bend finger bones less than halfway to breaking, the addition of a heavy fruit brings the bones dangerously close to failure. Counterintuitively, the model also predicts that heavier bones would cripple a bat. Its thin wing bones make up just 5 percent of the animal's weight, but if the bones' weight were doubled, the stresses on them would increase to dangerous levels rather than diminish. The wings' very lightness contributes to the safety of flight.

The computer model also makes clear that a bat's aerodynamics are far removed from those of fixed-wing airplanes. Unsteady airflow and flexible airfoils are the province of bat flight, and given the skittish nature of the average air traveler, those features are not likely to cross over to commercial aircraft. But because the complex movements of a bat's bones and skin do not require intricate muscular control, engineers still might try their hand at mimicking the bat's complicated but passive wing—designing a structure whose variable flight surfaces wouldn't require a motor at every joint. Perhaps, just as the wings of houseflies have been co-opted for microflyers, disembodied bat wings will also become an attractive option for flyers of medium scale—if not for Bruce Wayne in Gotham City, then for the designers of small, unmanned reconnaissance vehicles.

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A victim of filariasis cuts into his own leg to extract disease-causing nematodes (nineteenth-century engraving).

The Worm and the Parasite

Some tropical scourges call for a defense against an entire micro-ecosystem.

By T.V. Rajan

In the late 1960s, when I was a student at the All India Institute of Medical Sciences in New Delhi, my classmates and I had a microbiology professor who enjoyed taunting us as we struggled to identify badly preserved, poorly stained slides of parasite larvae and eggs. "You don't know what this is, do you?" he would say, cackling gleefully. "The eye does not see what the mind does not know." In truth, we scientists often don't understand what is staring us in the face. Like everyone else, we see what we see through the lens of a conceptual framework. The history of the treatment of filariasis, and of the research that has been done on the disease, is a perfect example of how a framework can guide, but also limit, our thinking.

The disabling and often disfiguring tropical disease known as lymphatic filariasis is one of the multitude of diseases for which mosquitoes are the vector. Elephantiasis—the grotesque enlargement of a limb, breast, or scrotum, caused by blockage of the lymph vessels—is one of its most conspicuous manifestations. According to the World Health Organization, filariasis afflicts some 120 million people worldwide, and more than a billion may be at risk of contracting it. Surpassed only by malaria as a cause of human suffering from disease, filariasis imposes an enormous burden of illness, lost productivity, and economic hardship on already-poor countries of the global South.

The nematodes that cause this nonlethal but devastating illness are threadlike parasitic worms, primarily of the species *Wuchereria bancrofti* and *Brugia malayi*. As with nearly every infection caused by a parasite, the precise mechanism that gives rise to the clinical disease is unknown. One can say with some confidence that none of the most obvious mechanisms are to blame: not the increasing population of larvae inside the human host; not the substances produced by the larvae, either living or dead; not the constant motion of the adult nematodes.

Transmission begins when a female mosquito siphons off a few microliters of blood from an infected individual. Two weeks later, when the ingested nematode larvae have developed into a stage that is infectious to humans, the larvae enter the insect's head. When she bites again, she transfers the nematode larvae to a second person. But the illness may remain asymptomatic for months or even years, leaving many of its carriers hard to identify.

On the basis of their own experiences in treating lymphatic filariasis, many of my medical mentors in India asserted that certain antibiotics were effective against the acute symptoms of the disease. Yet a quarter century ago (and, to a large extent, today as well) Western physicians pooh-poohed the Indian approach and held firmly to the admittedly logical, though in the end incomplete, position that infections caused by nematodes could not be treated with antibiotics. And here the story begins to take some twists.

Antibiotics are small molecules made primarily by soil-dwelling microorganisms of the genus *Actinomyces,* which compete with bacteria in the same ecosphere. These molecules can kill the bacteria that *Actinomyces* encounter, but they cannot kill eukaryotic cells—that is, any cell with a true nucleus enclosed by a membrane. Hence most living things made

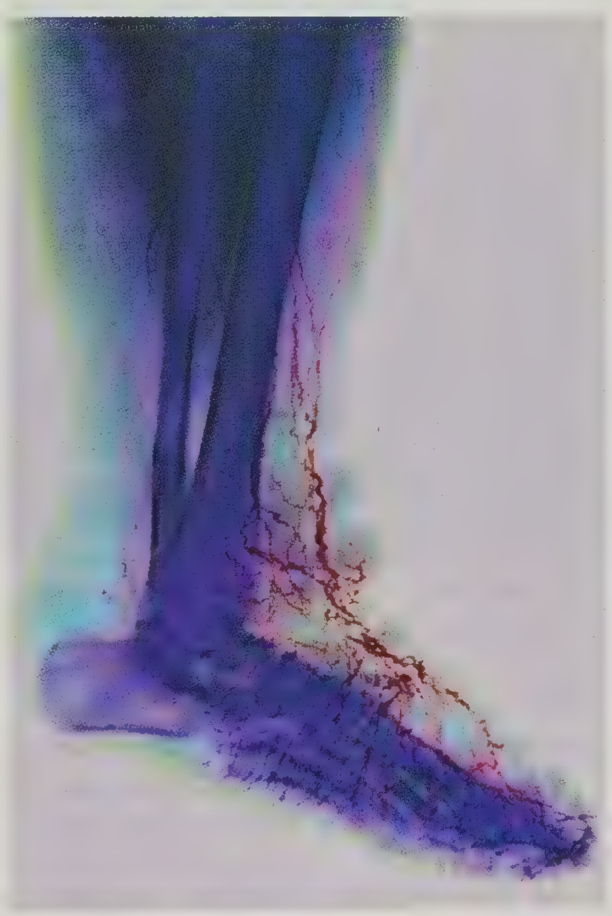
up of eukaryotic cells—and that includes nematodes, people, trees, and virtually anything else nonmicroscopic—are unharmed by antibiotics. So if antibiotics cannot destroy nematodes, how could the Indian physicians have treated a nematode-caused illness by administering them?

Filarial infections, it should be said, have some unusual features. Most people picture a patient with an infectious disease looking feverish, exhausted, and generally sick. Those and other "constitutional symptoms" of infectious illnesses are manifestations of the body's reaction to the invading microorganism; they are not caused by the infectious agent itself. When they detect the presence of alien organisms, the body's white blood cells synthesize proteins that cause a rise in temperature. The response is protective, enhancing the efficacy of the body's defense mechanisms. But one of the cardinal features of many parasitic diseases, particularly infections caused by nematodes, is the near-absence of constitutional symptoms. Nematodes can live in the body without eliciting such responses; even in the face of an active infection, many people do not experience acute symptoms.

Investigators have suggested that the longer two species live together symbiotically, the less chance that either one will disrupt the other's physiology. After all, the parasite needs a living home, not a dead one. Because many nematode infections seem to have coevolved with people over the aeons, most nematodes cause few if any disruptions of human physiology, hence few symptoms of infection. Yet many patients who contract filariasis suffer episodes of high fever, chills, trembling, and rigor. Acute filarial fever, in fact, can often look like an attack of another disease that is rampant in many of the same countries where filariasis is common: malaria.

Here is another oddity: While the nematodes are living out their four- to six-year life spans in their human hosts, they produce vast numbers of larvae that circulate in the blood. When a mosquito transmits some of those infective larvae to a new human host, the larvae migrate almost immediately to the person's lymph vessels. Because the lymphatic system is a critical component of the mammalian immune system, the nematode's choice of home base might seem peculiar: an invader doesn't usually position itself in the midst of a defending army. Yet the nematodes have clearly adapted to that hostile locale all too well.

The central peculiarity of lymphatic filariasis—the apparent usefulness of antibiotics in treating it—should have been resolved a quarter century ago. At that time, several groups of parasitologists interested in the microanatomy of filarial parasites examined the organisms with electron microscopes. One of the investigators, Wieslaw J. Kozek of the University of Puerto Rico School of Medicine in San Juan, noticed something he had not seen in other nematodes, whether parasitic or free-living. Within the vacuoles, or membrane-bound cavities of the nematode's cells, were even smaller organisms, resembling several genera of intracellular bacteria collectively known as rickettsia.



X ray of the swollen lower leg of a patient with elephantiasis. The swelling is caused by blockage of the lymph vessels (red in the false-color image).

Bacteria in this group lack cell walls and cannot survive outside the cells of the organisms they parasitize. Kozek not only concluded that what he had detected were bacterial symbionts; he also noted that the bacteria were more numerous in female nematodes, particularly in the uteri of the worms and in their developing embryos. Here, then, was a possible explanation for the effectiveness of antibiotics against filarial nematodes.

Kozek's findings, however, had the misfortune of being unfashionably morphological. Ever since the emergence of what is widely referred to as quantitative biology, any observation that cannot be expressed as statistical analyses or as DNA sequences has generally been greeted with skepticism, if not outright indifference.

As it happened, a more "quantitative" study was done by another parasitologist at about the same time, and it yielded a complementary, though inadvertent, result. Thomas R. Klei, a parasitologist at Louisiana State University in Baton Rouge, had initiated an experiment with the jird *Meriones unguiculatus*—a docile, gerbil-like desert animal that is susceptible to many of the same parasitic infections that afflict people. After being infected with filariasis, the jirds in Klei's experiment developed an unrelated skin infection that he treated with tetracycline, a broad-spectrum antibiotic. When he and his students examined the jirds at the end of the experiment, they found that the animals treated with tetracycline were free of nematode parasites.

The reigning biological dogma of the time made the finding thoroughly

puzzling. After repeating the experiment, with the same result, Klei contacted John W. McCall, a colleague at the University of Georgia in Athens, who had been supplying investigators with the infective larvae of a variety of nematode parasites for several years. It turned out that McCall, too, had noted that filarial parasites did not grow in animals treated with broad-spectrum antibiotics. But McCall told Klei that because he could neither explain nor understand his result, he hadn't published it.

Yet despite this cluster of independent, mutually consistent, and biologically exciting laboratory observations made by Western investigators—and despite the clinical successes achieved by practicing physicians in South Asia—no one picked up the thread until two decades later.

The story resumes in the mid-1990s, when Claudio Bandi of the University of Milan, an expert on bacteria living in insects, sought to determine how commonly other life-forms harbor bacteria within their cells. He was aware of studies done by Kozek and others, noting the presence of bacteria in filarial nematodes. Were these bacteria, Bandi wondered, related to the ones that live in insects? He and his colleagues chose a standard technique for answering such questions: they looked at DNA sequences that code for ribosomal RNA (rDNA). These sequences are present in the cells of all living organisms. Some of the rDNA sequences from heartworms were highly homologous to the rDNA of the arthropod-dwelling bacteria. Undoubtedly, those rDNA sequences had come from the genome of the bacteria that live in the worm, not from the genome of the worm itself.

A second reason for the renewed interest in filarial bacteria was the sequencing of entire genomes of biologically important organisms, such as the laboratory mouse, the worm *Caenorhabditis elegans,* and, of course, *Homo sapiens.* The filarial parasite *B. malayi* was part of the next wave of organisms whose entire genomes were to be sequenced. Even in the early stages of the work on the nematode's genome, Steven A. Williams of Smith College in Northampton, Massachusetts, and Mark Blaxter of the University of Edinburgh in Scotland noted that some of the sequences resembled the ribosomal genes of bacterial cells rather than those of eukaryotic organisms such as *B. malayi.* But because bacteria such as *Escherichia coli* are ubiquitous in molecular biology laboratories, the investigators initially thought the sequences were just contaminants.

Kill off the bacteria living in the worm, and the worm dies too.

It soon became clear, however, that the resemblances were not caused by contamination; Williams and Blaxter continued to extract bacterial rDNA from the nematodes even when the nematode samples were extremely clean. Even more telling, the sequences did not resemble the rDNA of *E. coli.* Instead, they were most homologous to DNA sequences from rickettsia, particularly from members of the genus *Wolbachia.* Combing through the literature to see if they could learn why the sequences were present, Williams, Blaxter, and others encountered the papers of Kozek, Klei, and McCall. Molecular biologists had rediscovered something that had been known to clinicians and morphologists for a quarter century.

Wolbachia bacteria infect at least 20 percent of all known insect species, disrupting their reproductive lives [*see "Invasion of the Gender Benders," by John H. Werren, page 58*]. For instance, the sperm of a male insect infected with *Wolbachia* do not function properly when they fertilize the ova of an uninfected female. But if a female insect is infected with *Wolbachia,* her ova are compatible with the sperm of both infected and uninfected males. Thus females infected with *Wolbachia* have a reproductive edge: they produce more progeny. Furthermore, *Wolbachia* is transmitted from the mother to her progeny, which suggests there will be more infected than uninfected progeny in the next generation. The process has no reproductive benefits for the insects, but it does ensure the rapid spread of the bacteria. Another of *Wolbachia*'s tricks is to turn some insects that were genetic males into sexually functioning females, and that leads to the same end result: an increase in the pool of infected females within the insect population.

All the symbiotic microorganisms being studied in current research on filariasis are *Wolbachia.* Most insects, however, seem to get along just fine without the bacterium. One insect species may harbor *Wolbachia,* whereas a second species, belonging to the same genus, may remain entirely uninfected. And when the bacteria within an individual insect are killed by antibiotics, the insect shows no obvious deleterious effects. By contrast, every individual filarial worm belonging to a species known to harbor *Wolbachia* has been found to be infected with the bacterium. And, as I suggested earlier, neither the worm nor the bacterium can live without each other. Killing the bacteria (by administering antibiotics) leaves the worms unable to develop, to mate, or to generate progeny.

A complementary finding reinforces the same conclusion. The genomes of the *Wolbachia* species that live within filaria are much smaller than the genomes of the bacteria that inhabit insects. That pattern is common when the relationship between two interacting species becomes fixed and mutually dependent. The smaller organism often jettisons substantial parts of its genome, having come to depend on the larger organism for most of its metabolic requirements.

The rediscovery of the fact that bacteria live within nematodes poses exciting medical possibilities, not only for elephantiasis but also for onchocerciasis, or river blindness, a disease that afflicts millions of people in sub-Saharan Africa. Much of the interest centers on two prescient suggestions made by Kozek and Horacio Figueroa Marroquin in their 1977 paper on *Onchocerca volvulus,* the filarial worm that causes onchocerciasis. First, they suggested that if the worm depends on the bacteria living inside it for some critical metabolic function, one could treat the disease by killing the bacteria. That suggestion has proved to be entirely warranted. Achim Hoerauf and his colleagues at the Bernhard Nocht Institute for Tropical Medicine in Hamburg, Germany, have shown that giving tetracycline to victims of river blindness destroys the *Wolbachia* inside *O. volvulus.* Tests on animals have led to the same result. In addition, a former student of mine, Heidi Smith, who is now a resident in internal medicine at the Dartmouth-Hitchcock Medical Center in Lebanon, New Hampshire, and I have shown that tetracycline prevents the filarial larvae from molting. Hence the antibiotic may be useful as a preventive as well as a treatment.

Kozek and Figueroa Marroquin's second suggestion was that some of the acute inflammation that accompanies filarial infections might be caused by the bacteria living inside the nematodes. Mark J. Taylor, a parasitologist at the Liverpool School of Tropical Medicine in England, and his associates have supported this hypothesis by demonstrating that the inflammation can be attributed to molecules called lipopolysaccharides, which are released by *Wolbachia* bacteria. More recently Eric Pearlman, a microbiologist at Case Western Reserve University in Cleveland, Ohio, and an international group of collaborators demonstrated that the severe eye pathology that occurs in patients with onchocerciasis might be caused by the same molecules.

The presence of *Wolbachia* in insects as well as in filarial nematodes raises an intriguing evolutionary possibility. Perhaps, at some stage long ago, the bacteria were transferred from insects to nematodes, since filarial nematodes reside in insects during some stages of their life cycles. But for reasons that are not yet clear, some filarial nematodes do not contain *Wolbachia*.

A larva (microfilaria) of the parasitic worm Wuchereria bancrofti, *surrounded by white blood cells, magnified 500 diameters.*

Physicians often disregard or even reject certain treatments because they don't "make sense" in the context of mainstream thinking. "The tomato effect: Rejection of highly efficacious therapies," a paper published in the *Journal of the American Medical Association* in 1984, addresses this troubling, though perhaps understandable, phenomenon within the medical community. In the paper, James S. Goodwin of the University of Texas Medical Branch in Galveston and Jean M. Goodwin note that British colonists refused throughout much of the eighteenth and early nineteenth centuries to cultivate tomatoes in North America, on the grounds that the fruit (a member of the nightshade family) was allegedly poisonous. Yet in Italy people had eaten tomatoes for hundreds of years with no ill effects. The Goodwins compare the episode to the rise, fall, and resurrection of such treatments as giving the plant extract colchicine for the pain of gout.

As the title of the Goodwins' paper implies, the treatments they studied were not among the questionable or even useless remedies that untrained or irresponsible "healers" may offer to desperate people. On the contrary, the treatments were provably effective. Clinicians simply avoided them because accepted theories of disease mechanism and drug action offered no explanation for their efficaciousness.

Today, of course, tomatoes are eaten across the globe. Could a similar reversal be in store for antibiotics in treating lymphatic filariasis? It is hard to understand the persistent lack of interest in exploring such a use of antibiotics unless what we have here is an instance of the tomato effect.

I cannot help but conclude that the scientific community is a microcosm of humanity—unable to appreciate the importance of anything until we are ready to do so, not seeing with the eye what we have not accepted with the mind. I wish it were different. I wish we were more truly scholarly, more humble about our limited understanding of the universe, more ready to accept that a number of things work despite our inability to explain why.

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Genetic Hoofprints

The DNA trail leading back to the origins of today's cattle has taken some surprising turns along the way.

By Daniel G. Bradley

On the move in Niger, northern Africa: Mounted pastoralists travel with their herd of humped, long-horned cattle.

The genes present in the 1.3 billion cattle living on the Earth today represent a stream of inheritance that stretches back 10,000 years. The founding event in the legacy of the domesticated farm animal was the capture of the formidable wild ox, or aurochs. Taming a long-horned beast six feet tall at the shoulder must have been a daunting task, but it was just one of a series of plant and animal domestications that forever changed the way most people live.

But just what is the genetic heritage of domestic cattle? Was more than one kind of aurochs brought under human control, and if so, how many ancestral species does that heritage encompass? How much variation is present in the genome? What experiences does its DNA encode to help the animal deal with heat, cold, hunger, thirst, disease, and all the other stresses of life? Answers to such questions do more than satisfy curiosity. Humanity's dependence on cattle runs deep, and our own well-being is therefore bound up with that of the animal. For example, if the selective breeding that has created a super milker should also inadvertently lead to vulnerability to a particular disease, how deep is the genetic reservoir that could still be called on to fight that vulnerability?

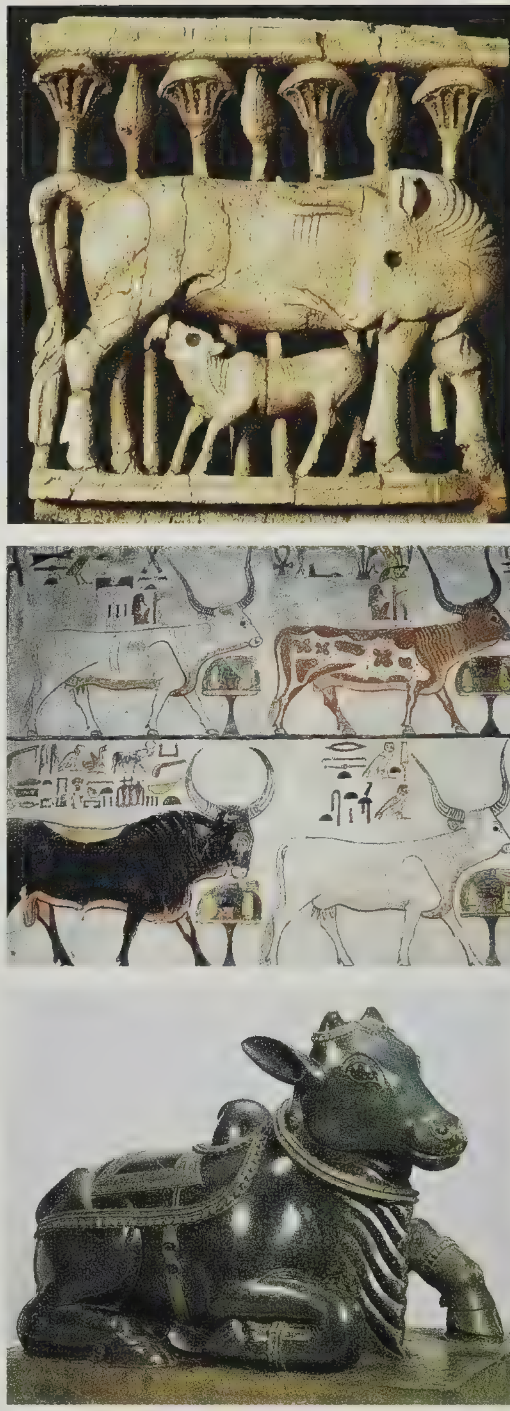
For the past dozen years my colleagues and I at the Smurfit Institute of Trinity College in Dublin have been tracing the genetic origins of modern breeds of cattle. The work has taken us from Great Britain to South Asia to the Sahara, and from modern factory farms to pastoralist societies. Guided by the signposts of DNA, we have virtually traveled back in time along the genetic stream, from the present to the ancient past, to the era when some determined bands of people first tamed an ox.

Before modern techniques of molecular genetics became available, the only meaningful information about how and when domestications took place came from archaeology. The study of those world-changing events, embedded as they are in prehistory, is a tricky business. Yet archaeozoologists have devised a number of ingenious ways of determining, for instance, whether dusty, 8,000-year-old collections of bones are the remains of hunted wild beasts or the former members of a domestic herd. Domestication is likely, for instance, if bone deposits show the animals died at roughly the same age. The conclusion also holds if the bones represent more males than females (herders often slaughter males but keep females to produce offspring) or if the bones indicate changes in structure and a slight decrease in size (features that begin to show up in animals after generations of domesticated life). In the

case of cattle, yet another feature of domestic service is diagnostic: the presence of certain kinds of wear and tear in joints or vertebrae, which indicates that the animals were once beasts of burden.

An archaeological site can be designated a domestication center only when excavations indicate that hunting gradually gave way to herding. Archaeologists have documented such a transition in the Fertile Crescent of the Near East. Extending outward from the land bounded by the Tigris and Euphrates Rivers, this region was the center of domestication for an unparalleled number of plant and animal species, including barley, oats, and wheat among the cereal grains, and the "big four" domesticated animals: cattle, goats, pigs, and sheep. But there is evidence that cattle were also brought under domestication farther east, in what are now Pakistan and India.

By tracing the ancestry of living animals, geneticists can verify and amplify archaeological findings, thereby giving a more detailed view of domestication and its history. Blood samples and hair follicles from individual cattle are used to provide samples of certain genes, such as the ones in the mitochondrion, the powerhouse of the cell. The DNA sequences of genes can then be compared. Mutations in DNA sequences accumulate at a pace that remains approximately steady over time. The known mutation rates of common sequences can serve as "molecular clocks," which enable molecular biologists to estimate when ancestral lines branched away from each other. The sequences my colleagues and I have studied indicate that hundreds of thousands of years ago—that is, long before any domestication took place—two distinct kinds of wild cattle emerged, both of which are represented in modern populations.



The characteristics of cattle arising in three ancient centers of domestication are realistically reflected in sacred and decorative arts. From top to bottom: a humpless cow and her calf from the Fertile Crescent, depicted in a Near Eastern ivory; Egyptian wall painting of humpless cattle, from the tomb of Nefertari; and Hindu sculpture of Shiva's sacred bull. Note the humped back of the Indian bull.

Patterns of genetic variation are like ripples in a pond, which persist even after the stone that caused them has sunk from view into the depths. The geneticist can judge from the size and direction of the ripples where and sometimes when a stone was dropped, as well as how big it was. Within the geographical distribution patterns of cattle genes, we have determined that not one but two big stones—corresponding to separate domestications of the two divergent kinds of wild ox—were thrown into the pond 10,000 years ago. The resulting ripples continue to expand and overlap.

Ever since Darwin, opinions had cycled between the one- and the two-stone scenario. Some scholars argued that all domestic cattle had a common origin in a single domestication center in the Fertile Crescent. Others believed, on the basis of archaeological evidence, that the cattle of the Indian subcontinent were separately tamed. Our work has shown that the cattle of Europe, northern Asia, and Africa all have closely related DNA sequences and that they all belong to a group that corresponds most closely to the humpless cattle known as *Bos taurus.* But the genes of the humped, zebu cattle native to India, known as *Bos indicus,* tell a different story. On the bovine family tree, zebu are ten times further removed from the three members of the *B. taurus* group than those three are from one another. The Indian humped cattle belong to a genetically distinct group of their own. So the genetic evidence firmly sides with the archaeological findings: early farmers, in what are now Pakistan and India, did indeed capture and tame their own zebu-like version of the wild ox.

Gene sequences can also be read as a record of how herding may have spread outward from those two domestication centers. Our genetic work had

indicated that European cows were related to the ones that were domesticated in the Fertile Crescent. But we wanted to find out whether they also carried a genetic inheritance from the aurochs that still inhabited Europe when cattle were being herded there. (The last remnant population of European aurochs was hunted to extinction in a Polish forest in 1627.)

In 2001, we managed to extract DNA gene sequences from six large aurochs bones discovered in Britain. The bones were between roughly 3,000 and 8,000 years old. The ones of more recent date were from wild oxen that had lived as neighbors of domestic herds then kept in Britain. Our analyses showed that the British aurochs sequences were closer to sequences present in *B. taurus* than to those of *B. indicus,* but they were quite different from any encountered in modern cattle. These wild oxen appear to have made no detectable contribution to the domestic gene pool; they did not interbreed with their domestic contemporaries. The forebears of European cattle, then, were wholesale importations from the Near East. Today a British cow's mitochondrial genes are much more similar to the genes of a cow—ancient or modern—from Syria or Turkey, than to the genes of the wild ox that used to roam the island.

Although we detected no other sources of genetic input in the DNA of modern European cattle, the animals themselves are outwardly much changed since their ancestors migrated from the Fertile Crescent. By selectively breeding for traits such as milk production, physical conformation, and even coat coloration, people have altered the appearance, size, and utility of livestock. After decades of scientific animal breeding, certain traits have been enhanced to an extraordinary degree. Milk production per animal has doubled in the developed world in the past twenty years, largely because of genetic manipulation. Top Holstein-Friesian cattle favored by large-scale dairy farmers can easily produce forty liters of milk a day; in contrast, a West African N'Dama cow may give only four.

Yet selective breeding, by definition, also narrows the genetic base of herds, and it may have side effects as well. Breeding for milk production, for instance, could lead to reproductive problems and increased susceptibility to disease. The predicament is not as extreme as it is in crop species, where the genetic base can be sharply narrowed. But the widespread use of artificial insemination in cattle inevitably implies that the male ancestors of most of the world's elite milking herds are all close relatives. Cattle raised on most European and North American farms today have a pedigree going back only to nineteenth-century founder animals of common breeds, such as Hereford, Holstein-Friesian, and Aberdeen Angus. And though the individual animals from which modern breeds were formed would have varied in appearance, most of the animals that belong to a particular breed today look remarkably uniform. Fortunately, though, there is still some diversity among European breeds, and valuable genetic resources may be tied up in less common breeds, such as the distinctive Scottish Highland and the Portuguese Alentejana cattle.

To find an exuberant variety of breeds, however, one has to look beyond the industrialized West, to regions where cattle have a place not only as commodities in the economy, but in the culture as well. The primacy of the cow is still intact not just in India (where cattle are considered sacred and are more numerous than in any other nation) but also in Africa. In African pastoral societies, milk, meat, and sometimes blood from cattle are major sources of protein; cattle dung provides both fuel and building material; and steers, or castrated bulls, are used as draft animals. Herd ownership can also symbolize status, and individual cattle can serve as large, mobile units of wealth. For example, bridegrooms often present cattle as gifts to the bride's family. Cows also serve religious or ritual functions. The Kapsiki people of northern Cameroon, for instance, keep a cattle breed (also

Although selective breeding for high meat and milk production has marginalized distinctive European breeds, such as the hardy Scottish Highland (right), variety thrives in Africa, where cattle such as the Kuri, of Chad, are prized (left).

known as Kapsiki) specially for the skins, which are made into burial shrouds.

Such cultural intimacy between the people of Africa and their cattle does not mean that African herders refrain from any selective cattle breeding. But Africans breed their herds without the obsession for uniformity that has emerged in the West. One of the most evident traits that African herders select for is extreme horn size. The enigmatic Kuri cattle, herded near Lake Chad in north Africa, bear horns of enormous length and girth. When these cattle move side by side in the herd, their hollow horns knock together, producing a characteristic resonant sound. The horns are selected for their appearance rather than any utility. Ankole cattle, from the great lakes region of East Africa, are also bred for horn shape and size. Not surprisingly, the animals are prized status symbols.

According to our genetic analyses, African cattle originated neither from Indian humped cattle nor from Near Eastern cattle. Those findings support the separate-origins theory of cattle domestication favored by archaeologists, who had maintained that in Africa, too, cattle domestication was local. Our results confirm that African cattle stem from the domestication of a *B. taurus* type of wild ox that inhabited northern Africa when the Sahara region was much less arid than it is today. It may even be the case that the distinctive pastoral lifestyle of African tribes such as the Masai is of tremendous antiquity, and could pre-date the capture of cattle and development of milking in the Fertile Crescent.

Although the earliest African cattle were of the *B. taurus* type, modern African breeds show multiple influences, traceable through their genetic history. I recently joined the geneticist Olivier Hanotte and his coworkers at the International Livestock Research Institute in Nairobi, Kenya, in a study that was part of a worldwide effort to chart genetic variation in cattle breeds, in the hope of conserving diversity.

Hanotte sampled the genes of fifty indigenous breeds of cattle in twenty-three countries across the length and breadth of Africa. Then, with a technique called principal-component analysis, we were able to peel away the various overlays of genetic variation caused by interbreeding, as they appeared across the continent—rather like peeling the layers of an onion. As each overlay was removed, we exposed a new, previously unseen trend, or pattern of variation. One major trend was the dispersal over millennia of the original *B. taurus*-type cattle from the Sahara region to the forests of West Africa and down to the southern cape. A second, minor genetic trend was a trickle of Near Eastern and European cattle into the continent, where they mixed with native breeds.

The third and most pronounced trend in our genetic data, however, pointed to a great influx into Africa of zebu-type, *B. indicus* cattle from South Asia. A herd in Sudan, for instance, can now carry mitochondrial DNA from the domestication of a northern African wild ox, an event that may have taken place only a hundred miles from Sudan, but more than 7,000 years in the past. The same herd may also include some genes that have leaked southward from the Fertile Crescent in the same period. But strikingly, most of the genes in the Sudanese herd are likely to be of the *B. indicus* type. And the cattle are likely to be humped, like Indian zebu.

When we overlaid the gene types on a map of Africa, we discovered that the numbers of *B. indicus* genes peaked on the east coast. The clusters suggest that zebu were first imported into Africa in large numbers by sea, rather than via an overland route such as one crossing the isthmus of Suez. Perhaps the humped cattle were brought first to Arabia, then on to East Africa. We also determined that the most purely *B. indicus* of African breeds live on the island of Madagascar, a finding that also supports the idea that the Asian cattle came to Africa by sea. The trade between Africa and India seems to have been ancient and reciprocal. African cereals such as sorghum and finger millet appear in India as early as the second millennium B.C., about the same time *B. indicus* may have first appeared in Africa.

Since their arrival in Africa, Indian cattle genes have thrived and through interbreeding, have spread throughout the continent. Zebu are generally well adapted to hot and dry environments, a

Masai homes clustered around a corral in East Africa show that cattle are literally at the center of village life.

boon in African regions that are becoming increasingly arid. And in the late nineteenth century, when the cattle disease rinderpest became epidemic and decimated *B. taurus* herds, zebu genes conferred some resistance.

In an age when most cattle in the developed world have a slim family tree, humanity should treasure, and perhaps will come to be thankful for, the rich weave of ancestry that persists on the plains of Africa. Pastoral societies also preserve the cultural importance of this largest of domesticated species. In Western societies, this cultural element has mostly disappeared from people's everyday lives. Cattle retain their significance only behind the fenced-in properties of agribusinesses and the well-guarded entrances to commodity-trading floors.

Here in my home, Ireland, the economy was dominated for millennia by cattle farming. The system stretched back to the time of the herders who built the stone-walled fields of Céide, in the west of the island, fields that have lain buried under peat bogs for 5,000 years. The Irish word for a road, *bothar,* means a path wide enough to accommodate a cow. And in the wider cultural setting cattle have literally been the alpha, if not the omega, of the Western world. After all, the first letter of the alphabet you are now reading had its genesis as a symbolic representation of an ox. □

In the Indian city of Bhuj, forty miles from the epicenter of a recent earthquake, stands the half-ruined city palace, or darbargarh, *of the maharajas of the district of Kachchh.*

Shaken to the Core

Mid-continental earthquakes can be even more damaging than the ones at the boundaries of tectonic plates. The great Indian earthquake of 2001 is a benchmark for geologists seeking to understand how they happen.

By Susan Hough and Roger Bilham

In the westernmost corner of India, south of a huge salt marsh known as the Rann of Kachchh, lies the old walled city of Bhuj, administrative headquarters of the district of Kachchh. To a Westerner, even a traveler equipped with a Lonely Planet guidebook, the area seems remote. A single train arrives in Bhuj each day; rarely does a tourist disembark. Yet, like most of India, the city and surrounding region are densely populated and rich in architectural heritage.

Two years ago these human and architectural riches became, in an instant, the preconditions for tragedy. On January 26, 2001, a magnitude 7.6 earthquake struck India about forty miles northwest of Bhuj. The quake was the first major temblor to take place on land, and away from a tectonic plate boundary, since the invention of the modern seismometer in the 1880s. It killed more than 18,000 people and wrecked hundreds of thousands of buildings across the Indian state of Gujarat.

Deep cracks in a wall, caused by the earthquake's severe shaking, flank the portrait of a nineteenth-century ruler of Kachchh.

Less than a year and a half later a much smaller, magnitude 5.1 mid-continental earthquake hit New York State just south of the Canadian border. This one, the Au Sable Forks quake of April 2002, did little damage, but its unfamiliar rumblings were felt all over the northeastern United States. A temblor that size in Los Angeles would barely be noticed in earthquake-jaded San Diego, a hundred miles away.

Gujarat and New York are on virtually opposite sides of the globe, but in geological terms they have much in common. Unlike California or Alaska, neither Gujarat nor New York is situated atop a seismically active boundary between the Earth's great tectonic plates—rigid blocks of the planet's brittle outer layer that can measure thousands of miles across but are often less than a hundred miles thick. Given such a substantial platform, one would not expect either state to undergo many earthquakes—certainly not as many as take place in the regions situated above active plate boundaries.

But the earthquakes that do strike places like Gujarat and New York have a particularly long reach. In regions along plate boundaries—coastal California and Alaska, but also the Himalaya and the Andes—the crust is a jumble of once-distinct terrains. Over geologic time, as tectonic plates have ground past each other, rocks have been cracked, ruptured, and folded, thereby mixing and mangling ancient terrains. Earthquake waves cannot propagate efficiently in such a complex, fractured setting. In regions that lie within plates, however, the underlying crust is older, less fractured, and less complicated, and the waves reverberate over much greater distances from an earthquake's epicenter.

The Bhuj temblor strongly shook the ground as far as 300 miles from its epicenter in the district of Kachchh. High-rises toppled in Ahmadabad, a large industrial city almost 200 miles away. In the hardest-hit towns and villages, people and buildings alike were thrown down violently. Writing to BBC News Online, a resident of one devastated town described the scene as she and her father

stood on the balcony of her apartment block, watching everything around them shaking and crumbling. "We were in the jaws of death waiting for it to gulp us," she wrote. "Any small jerk could have caused the building to collapse."

Bhuj was truly a shock heard round the world, a wake-up call both for its horrific immediate effects and for its even more frightening implications. Earthquake damage reflects not only the magnitude of a main shock but also a region's population density and the vulnerability of its buildings, roads, and other structures. As recently as October 2002 a magnitude 5.9 earthquake in the southern Italian village of San Giuliano di Puglia took twenty-nine lives; three days later a magnitude 7.9 quake in Alaska claimed none.

It is sobering to contemplate what might take place when the next major earthquake hits the Himalayan region. The combination of potentially great magnitude, efficient earthquake wave propagation, crowded cities, and fragile buildings could threaten the lives of tens of millions of people. For comparison, consider the effects of the magnitude 7.8 shock that took place in the industrial city of Tangshan, China, in 1976. Tangshan has the unhappy distinction of being the only large city to have suffered a direct hit from a major earthquake in the past hundred years; the death toll there may have been as high as 750,000, though the official tally is closer to 250,000. A future large Himalayan earthquake could cause an immediate six-figure death toll in India and Pakistan—not to speak of the likelihood of widespread epidemics, the obliteration of costly and essential infrastructure, and the possible release of radiation from nuclear power plants.

The Bhuj earthquake offers lessons for other regions as well. Modern seismic monitoring and analysis have established it as the standard against which to compare anecdotal descriptions of other large mid-continental quakes in the historical record. Among the most important such earthquakes, at least for North Americans, were three powerful shocks that struck the southeastern corner of Missouri, near the town of New Madrid, in 1811 and 1812. The New Madrid earthquakes were strong enough to temporarily reverse the course of the Mississippi River and cause damage as far away as coastal South Carolina [*see "The Aftershocks That Weren't," by Susan Elizabeth Hough, March 2001*].

To probe the full implications of what happened in western Gujarat in 2001, geologists are seeking to understand as much as possible about the region's earlier geologic history. The ancient port of Debal, on the Indus River delta, was destroyed in A.D. 893 by an earthquake, and another temblor is thought to have submerged the nearby city of Samaji in 1668. In 1819 an enormous, magnitude 7.8 earthquake known as the Allah Bund (Dam of God) hit Kachchh. Less than two centuries later came Bhuj. And between the Allah Bund and Bhuj events there were six earthquakes in Gujarat greater than magnitude 6. Moreover, recent excavations of mutilated skeletons, which seem to have been buried suddenly under a jumble of strata, have led some scholars to conclude that the highly organized Harappan civilization of the Indus Valley, which flourished in the fourth and third millennia B.C., may also have suffered earthquake devastation.

The Allah Bund and Bhuj earthquakes were of roughly the same strength, and they generated strikingly similar patterns of damage. Captain James MacMurdo, the first colonial administrator of Kachchh, experienced the 1819 event firsthand; his reports echo vividly across the centuries: "Many of the villages . . . are reduced to heaps of rubbish," he wrote. From Bhuj he relayed accounts of "a violent undulating motion, so that it was with difficulty [that people] could keep [their] legs."

The two earthquakes are now thought to have ruptured closely neighboring faults, cracking through the earth's crust. Like the Bhuj quake, the Allah Bund largely reduced the two closest towns, Bhuj and Anjar, to rubble. It also created a broad, towering ridge—a natural dam—across the nearby (and now dry) Puran River. Downstream from the

ridge the land sank, leaving an enormous depression that flooded with seawater. A fort that had stood on the riverbank south of where the ridge formed became a ruin surrounded by seawater for fifteen miles in every direction. (Today the structure is invisible, buried beneath a crust of salt.) Survivors inside the fort were ferried to the shores of the new lake; by the time they reached that relative safety, local residents were pulling both the living and the dead from the remains of their villages. Not only did the ridge dam the flow of freshwater from the north; it also put an end to trade along the Puran River.

To anticipate and help prepare for future earthquakes, earth scientists rely heavily on data from past events. Mostly they analyze data from seismometers deployed around the globe, as well as data from the two dozen satellites that make up the Global Positioning System (GPS). The satellites can give positions so accurately that geologists can monitor the long-term deformation, or warping, of the earth's crust with extraordinary accuracy: the glacially slow motions of tectonic plates can be measured and tracked to within the thickness of a fingernail.

Many buildings in the center of Bhuj had stone walls and concrete roofs, a combination that proved particularly vulnerable to damage from shaking.

Of course, no such data are available either for the Allah Bund or for any of the other large mid-continental earthquakes in recorded history, including the New Madrid quakes in North America. Many important seismic events simply took place too long ago to have left behind evidence from which earth scientists can extrapolate.

Yet even without seismic recordings, one can sometimes infer the subsurface character of an earthquake from the wrinkles it creates at the surface. Much of what is known about the source of the largest New Madrid shock has been inferred from descriptions of a small region of uplift that created a waterfall on the Mississippi River. In the same way, the Allah Bund ridge has provided clues about the mechanism and size of that earthquake.

Various kinds of tectonic boundaries of the Indian plate reflect its current northeastward motion (arrow). Moving at 1.7 inches a year (relative to the Eurasian plate), the Indian plate is pushing up the Himalaya and creating the high Tibetan plateau.

The New Madrid and Allah Bund quakes were strikingly similar in ways other than the surface uplift they produced. Sizable mid-continental earthquakes tend to strike in ancient, fault-riddled zones of relatively weak rock, which arise where landmasses begin to part. (One of the most conspicuous contemporary examples of an ongoing parting is the splitting of the African plate along the East African Rift System, which is creating the deep lakes that run from Lake Albert to Lake Tanganyika.) Numerous subsidiary cracks develop in the crust, widening along with the main rift over geologic time. Some of the cracks link up, ultimately forming deep lakes and new oceans; others

languish, but they can be reactivated by new tectonic forces millions of years later.

Both the Allah Bund and the New Madrid earthquakes resulted from ruptures along steeply inclined cracks, or thrust faults. Such ruptures make it possible for a block of crust to ramp up over adjacent rock. That slippage between blocks of crust temporarily relieves the stresses that led to the ruptures in the first place, but the slippage also creates new points of stress. In fact, every large earthquake leads to a substantial redistribution of the stresses in its immediate locale, raising the specter of future redistributions, and future shocks, on adjoining faults.

Unfortunately, such a broad-brush picture offers little insight into the where and when of the next earthquake: the geological understanding of stress redistribution is still in its infancy. Any hope of making useful forecasts will require more data from large earthquakes. For example, even after nearly two centuries of study, geologists cannot say when the next large earthquake will strike the New Madrid area. And if events in that area follow the pattern of events in western Gujarat, the next great central U.S. earthquake might take place, not in New Madrid, but in the southwestern corner of Tennessee—close to the city of Memphis—or perhaps near the southwestern corner of Indiana, where a magnitude 5.0 quake struck in June 2002.

An earthquake as powerful as the one that struck western Gujarat in 2001 rings the earth like a bell, and geologists respond to the seismic signal as if it were a fire alarm.

An earthquake as powerful as the one that hit western Gujarat in 2001 rings the earth like a bell. The waves it generates cannot be felt by people living in other regions of the world, but seismic sensors virtually anywhere on the globe can detect them. For geologists, the seismic signal of a big earthquake is like a fire alarm, instantly causing concern and impelling a quick response.

Geologists rushed to Kachchh, expecting to map the surface pattern of faulting. Large earthquakes generally cause a visible giant crack or a displacement of the surface rocks and soil. But the investigators in Kachchh found only a few minor cracks and bulges, all of which were attributable to the effects of violent shaking rather than to deeper breakage along a fault. In spite of the temblor's substantial size, the slippage along the fault stopped propagating well before it reached the earth's surface. Geologists found nothing to map except relatively modest secondary ground disruptions.

But there are other ways to reconstruct the details of movement along a deep fault, a study worth pursuing on both academic and practical grounds. Earthquakes of the same magnitude—quakes that release the same amount of energy overall—do not always generate fault ruptures of the same size, and differences in the size of a rupture lead to differences in the shaking of the ground. The longer the rupture, the lower the dominant frequency of its vibrations. The same principle determines the pitch of an organ pipe or a string on a double bass: the larger the pipe, or the longer the unstopped string, the lower the note. Even though a musical instrument is enclosed in air and a rupture is enclosed in rock, both transmit sound waves through their respective mediums.

As it happens, buildings are generally most vulnerable to shaking within a fairly narrow range of frequencies; they absorb vibrational energy primarily at their own resonant frequencies, just as a plucked string does. The kinds of structures most common throughout Gujarat—masonry buildings typically one story high and almost never higher than ten stories—are affected primarily by vibrations of between one and ten cycles a second. That is a fairly high frequency for a large earthquake. Recent investigations reveal that earthquakes of magnitude 7 or greater that have relatively small ruptures will shake particularly violently at frequencies between one and ten cycles a second. The severe damage caused by the Bhuj earthquake, coupled with its magnitude, suggested that the quake had an unusually small rupture area.

Without a surface rupture to measure and assess, seismologists could turn to three other kinds of data: the distribution of aftershocks; the "strong motion" seismic recordings from the vicinity of the event; and deformations, or warping, of the surface. Data on aftershocks and on strong motion from a main shock come from records made by seismic equipment deployed before an earthquake takes place. Deformation data are most valuable if the region was surveyed before the quake.

Following the Bhuj shock, seismologists faced frustration at nearly every turn. Few modern seismometers were in place in Gujarat at the time of the quake. In spite of its history of earthquakes, the region was thought to be less vulnerable to damage than are areas in which large or frequent quakes have hit more recently. One such area is the 1,500-

mile arc of the Himalaya, which lies along the boundary of two colliding tectonic plates. (The Himalaya, the world's highest mountain range, is still being squeezed upward by immense pressures as the northeastward-moving Indian subcontinent collides with the rest of Asia.) Lacking recordings of the Bhuj earthquake's strong motion, investigators had no detailed seismic evidence of the patterns of motion along the fault. Moreover, the positions of the quake's aftershocks could not be pinpointed until teams of seismologists were able to analyze data gathered with portable instruments during the weeks and months following the main shock.

What saved the day for the investigators was a detailed survey of Gujarat—part of the Great Trigonometrical Survey of India—that was completed in the mid-nineteenth century. Thousands of engraved stone markers, placed deep within pillars, had been installed on hilltops during the heyday of the British Raj to enable accurate mapping of the region. The recorded positions of the markers established a baseline for geologists, who could then measure how much the markers had shifted after the quake. So when Indian, Pakistani, and U.S. teams of earth scientists sped to the region in early 2001, they brought along both high-tech GPS surveying units and quaint Victorian descriptions of the survey points' positions.

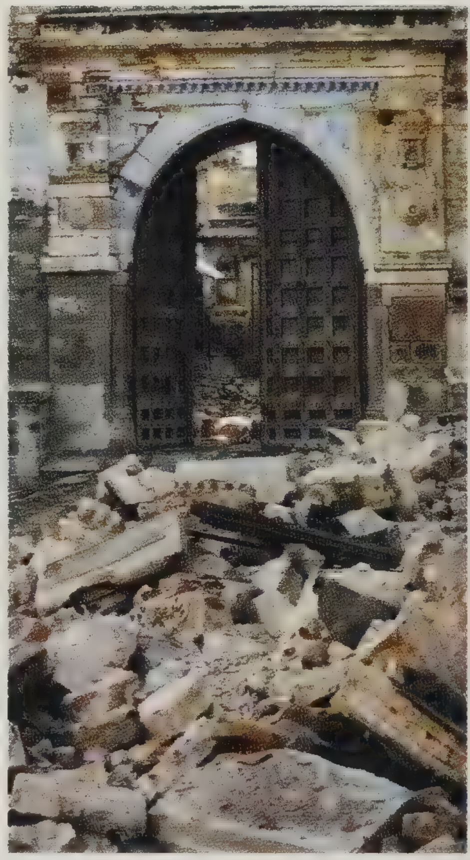
The heavy dome of a funerary monument, or chhatri, *outside the walls of the old city of Bhuj still rests on its supporting columns, despite having rocked back and forth during the earthquake's violent shaking.*

Although simple in principle, the field investigations were quite complicated in practice. Some of the markers had been destroyed by the violent shaking of the pillars surrounding them; many others had been lost to scavengers and small children during the preceding century and a

half. Nevertheless, the scientists located a dozen of the old markers; several had shifted more than three and a half feet. An analysis of the altered positions confirmed that, deep in the crust, a fault some twenty-five miles long had slipped, on average, about twenty feet—a massive amount. The rupture of the fault had terminated more than three miles below ground.

Months later, after studying their seismometer data to infer the locations of aftershocks, seismologists also concluded that the rupture area was deep and surprisingly compact. The combination of a relatively short rupture and a large amount of slippage, as in the Bhuj quake, leads to unusually strong stresses at the edges of the rupture. Those stresses can stretch or compress rock well beyond its breaking point. Indeed, a flurry of aftershocks took place around the underground Bhuj rupture. The positions of the aftershocks seemed to confirm that the stresses had been great enough to cause extensive cracking and fragmentation of the crust surrounding the parts of the fault that had moved during the main quake.

In the end, modern data gave earth scientists a fairly good view of the underground processes that led to the earthquake. But assessing the severity of shaking at the surface was an entirely different kind of challenge, and it was the shaking, after all, that had caused the damage. Some disruptions at the surface—sand blows, for instance, which are literally fountains of sand that erupt at the surface like geysers—were widespread, and geologists were able to document them. But such effects yield at best only indirect information.



A finely crafted doorway in the Bhuj darbargarh's *Ranivas Palace, built in the seventeenth and eighteenth centuries, remains largely intact.*

Because of the almost complete lack of direct, immediate seismographic data on the Bhuj earthquake itself, earth scientists turned instead to a time-honored source of information: personal anecdotes describing damage and other effects. By collecting accounts in the field as well as compiling the descriptions published in the media and on the Web, investigators were able to map the shaking during the event. The effects ranged from the near-total collapse of villages to barely perceptible shaking felt by residents of India's east coast.

Such accounts, properly weighed and interpreted, can yield an estimate of an earthquake's intensity—the severity of shaking at a particular location—typically stated as a Roman numeral between I and XII. Near the Bhuj main shock the inferred intensities reached IX to X, strong enough to cause catastrophic damage to masonry structures.

These investigations helped establish the Bhuj earthquake as a yardstick and made it possible to assign more accurate magnitudes to the largest quakes at New Madrid: between 7.2 and 7.5, almost as large as the earthquake that devastated western Turkey in 1999.

The historical record of earthquakes in Gujarat is also prima facie evidence that a cluster of major shocks can occur in areas removed from active plate boundaries. The devastation in Bhuj provides clear evidence that such shocks can cause enormous damage.

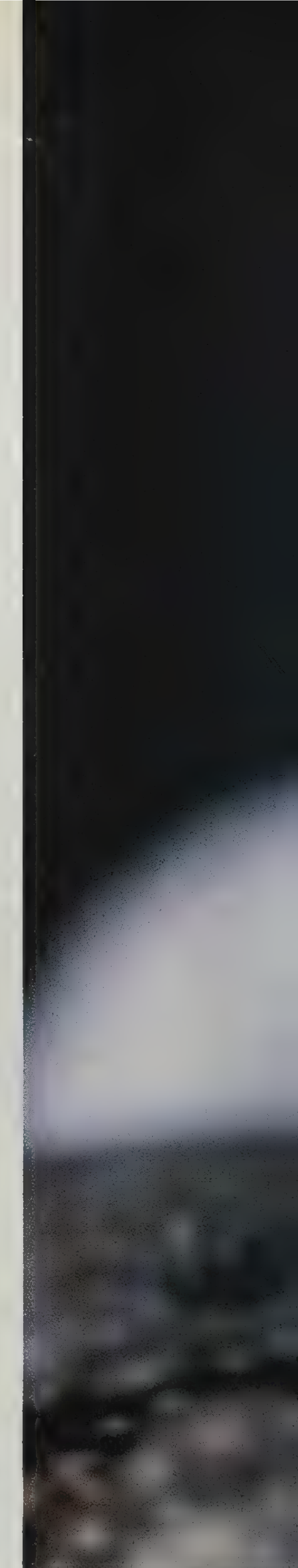
If the lessons of Bhuj are sobering for North America, they are staggering for India and Pakistan. Home to 1.2 billion people, the two countries—though riven by social, political, and religious upheavals both internal and external—jointly face the imminent deadly hazard of a great Himalayan earthquake. The ongoing collision between the Indian and Eurasian plates creates enormous stresses throughout India, which account for the shocks away from the plate boundaries. And the sustained uplift of the Himalaya themselves is accompanied by great earthquakes that represent a common enemy of countries along and near the mountains' arc. Recent calculations indicate that several earthquakes as large as magnitude 8 are due along fully half the length of the Himalaya.

Humanity has never had to face potential earthquake devastation of this nature and scale. Multiple urban targets of great size and vulnerability have never before existed in areas where strong seismic shaking is common. As a result, what was impossible even half a century ago is now not only possible but, in some places, probable. As horrific as it was, the Bhuj earthquake was really only a warning shock. Its legacy will depend on the extent to which the world heeds the warning. □

Biosphere III

A ninety-year-old inadvertent experiment in tropical biodiversity is unfolding on several islands created by the construction of the Panama Canal.

Photographs by Christian Ziegler
Story by Egbert Giles Leigh Jr. and Christian Ziegler



How does a tropical forest manage to stay green despite an onslaught of leaf-eating sloths, monkeys, porcupines, and iguanas, not to mention a plethora of leaf-chewing and sap-sucking insects? Most flowering plants defend their leaves with toxins that deter all but the most specialized pests. Animals that the plants recruit as seed dispersers and pollinators enable some of the young plants to escape notice until they are large enough to survive the depredations of specialist pests. The animals also ensure that mature plants are cross-pollinated even if other members of the species are not close by.

In the Jurassic period, 150 million years ago, a few square miles of tropical forest harbored relatively few species of plants: conifers, cycads, seed ferns, and the like. Dependent on cross-pollination by wind, members of a species had to grow near each other, and so the pests, too, spread easily from one plant to another. Plants therefore had to invest heavily in pest resistance, leaving fewer resources for quick growth. Fifty million years later, aided by animal pollinators, a baroque diversity of faster-growing, flowering plants entered the tropical forest. After the dinosaurs died out, they became dominant.

Damming a tropical river, however, creates a reservoir that reduces forest to island fragments. Small islets cannot support resident pollinators and seed dispersers, and many of those essential reproductive helpers will not cross the water to visit. On such islets, a Jurassic world returns, where plant diversity plummets and animals help themselves to plants without helping them in any way.

What happens on a large fragment? Barro Colorado, in central Panama, is a six-square-mile island that was cut off from the mainland when the Chagres River was dammed in 1912 to form part of the Panama Canal. Since then, the island has been losing species. At least seven mammals have disappeared, including the herds of white-lipped peccaries. Various insect-eating birds that nested or foraged on the ground have vanished. The large ocellated antbird is also absent: it can only catch insects flushed by army ants, and one year the ants did not swarm in large enough numbers to support it. Biologists owe such details to a field station built on the island soon after it was declared a biological reserve in 1923. Since 1966, when the station became part of the Smithsonian Tropical Research Institute, the island has become one of the world's best-studied tropical forests.

Barro Colorado is large enough to show how a tropical forest supports a diversity of plants and animals. Nearby islets of less than three acres, however, support no resident mammals at all. They have no agoutis to store seeds by burying them, so seeds of many tree species are ravaged by insects, and these tree species are dying out. Although Barro Colorado still holds many secrets, it has made clear that forest fragmentation has intricate repercussions.

A wasp lingers after emerging from one of the white cocoons attached to the mottled surface of a sphinx moth caterpillar. In a tropical forest, "the enemy of my enemy is my friend." Plants muster various defenses of their own to ward off insect herbivores, but they also benefit from a pest's natural enemies. Among these allies are wasps whose larvae live in and on the larvae or adults of other insects, sapping their strength before eventually killing them. The white cocoons here belong to such a parasitoid, a wasp in the family Braconidae. Some parasitoids are themselves subject to such attack, by hyperparasitoids. The emerged wasp is actually one that has parasitized the wasp larva in one of the cocoons. ("Great fleas have little fleas upon their backs to bite 'em/ And little fleas have lesser fleas, and so ad infinitum.")

A cicada has just emerged from its larval skin after spending years underground as a larva sucking xylem sap from roots. This kind of sap is a diluted food, and so a cicada larva grows slowly. When it finally crawls out of the ground one night, it climbs a plant, hooks onto it, and metamorphoses into an adult. The mature cicada continues to live off sap while pursuing its brief adult life seeking a mate. (An insistent noise, rather like the sound of a high-pitched buzz saw, that pervades the forest is the male advertising its presence.) Insects that suck plant juices, such as cicadas, leafhoppers, and aphids, slow plant growth every bit as much as leaf-chewers do, but they leave no visible evidence of their depredations.

Seemingly covered in moss, a walking stick (Autolyca *sp.*) *is a master of camouflage. Stick insects are among the many leaf-eaters that plants must contend with. A tropical forest such as Barro Colorado not only includes many kinds of trees, but the various species are also well mixed over the landscape. The most logical explanation for the intermingling is that the insects that specialize in consuming a particular species are likely to kill any young plants growing close to their parents or to others of their kind. A tree species can maintain a scattered population by relying on friendly insects and other animals to pollinate their flowers and spread their seeds across long distances.*

Many plants, including this Croton billbergianus *tree, have nectaries on the bases of their young leaves that attract ants (a nectary is visible here near the ant's head). The ants can scare off some potential herbivores. In the case of this* Croton, *however, some resident* Thisbe irenea *caterpillars have induced the ants to leave them in peace. The caterpillars curry favor by drinking the plant's nectar and turning it into a liquid the ants prefer. Accordingly, the ants let the caterpillars devour the leaves at will and even defend the caterpillars against some of their enemies. The caterpillars have structures on their bodies that attract ants with sound, and when danger threatens, they can even summon their defenders by releasing chemicals that mimic the alarm signals of ants. Another plant whose nectaries attract ants is the swollen-thorn acacia* (Acacia melanoceras), *a tree with bulbous hollow thorns where the ants can nest. An acacia's resident ants—members of the species* Pseudomyrmex satanicus, *justly named for its obnoxious stings—chew off the tips of encroaching vines, repel herbivores, and maintain a clearing around their plant's base.*

A fig fruit starts out as a flower head, then turns itself outside in to form a ball, or syconium, that is lined on the inside with flowers. The wasp pictured here specializes in laying its eggs in the syconium from the outside, with its long ovipositor, and leaves the pollinating of the flowers to another species of wasp. Each species of fig tree—in Barro Colorado there are eighteen—has its own species of pollinating wasp. Pollinators enter the syconium through a hole at one end and lay eggs in about half the flowers. The larvae grow inside the developing fig seeds, no more than one to a seed. When the adult wasps emerge from their seeds, they mate among themselves inside the fruit. The males then chew a hole in the syconium's wall, and the fertilized females—dusting themselves with the pollen that the flowers are only now producing—fly off in search of new trees in which to lay their eggs.

To feed its pollinators, each fig species must always have some trees with fruit ready to pollinate, whether or not the season is propitious for fig seedlings. Moreover, the trees must ensure that the fruits don't overheat in the sun and kill the wasps inside. Species that produce relatively large figs, which cannot shed heat to the surrounding air as readily as small figs can, provide a steady stream of water to their fruits throughout the day, which cools through evaporation. The trees rely on other animals to eat their ripe fruit and disperse the many seeds that have been spared by the wasps. Trees with red fruit are served mainly by birds, which are attracted to the color red. Species with green fruit depend mainly on fruit-eating bats, which they attract during the night with a distinctive scent.

Fig trees are often "keystone species"—disproportionately important to the maintenance of other species—in tropical forests of the Americas and Asia. Fig trees do not invest heavily in defenses against the herbivores; instead they grow fast, produce an abundance of nutritious foliage and fruit, die relatively young, and rot quickly when dead.

The poisonous green spines of this caterpillar, from the moth family Limacodidae, discourage potential predators such as birds. Caterpillars are a diverse and abundant group of leaf eaters. Many feed on only one genus or species of plant, collectively enhancing tree diversity by preventing any one species from crowding out the others. A casual visitor to a tropical forest may not spot the caterpillars feasting on the vegetation, but only an upward glance is required to see their handiwork: tree leaves that have holes and ragged edges or that have been reduced to a delicate network of veins. One might also experience what sounds and feels like a gentle rain—but it is the falling of the frass, or feces, of leaf-eating caterpillars overhead.

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A Culex pipiens *mosquito, newly emerged from its pupal skin: Males of the species, if infected by* Wolbachia *bacteria, produce sperm that is incompatible with the eggs of uninfected females. Other* Culex *species have protozoan infections that are transmitted through the eggs and kill the male larvae but not the female ones.*

Invasion of the Gender Benders

By manipulating sex and reproduction in their hosts, many parasites improve their own odds of survival and may shape the evolution of sex itself.

By John H. Werren

Sex is fraught. Every teenager can attest to the havoc it wreaks—and to its unique power to change a life. Of course, that's one of life's lessons that survive far beyond the teenage years—and far beyond the human condition. To anyone who explores the ramifications of sex in other species, its permutations seem bottomless. In recent years, the study of evolution, of parasites, and even of disease has often led back to sex. Particularly fascinating are the ways in which some parasites manipulate sex and reproduction in their hosts—stories of exploitation and subterfuge that have amazed and astonished even life scientists long jaded by tales of biological intrigue.

Take the case of *Nosema granulosis,* a protozoan that often resides within the cells of *Gammarus duebeni,* a small shrimp that lives in intertidal pools along the coasts of Europe. When an infected mother shrimp reproduces, the protozoans hitch a ride in the cytoplasm of her eggs and thereby infect her offspring. But if the protozoans infect a male shrimp, they cannot readily infect his offspring by hitching a ride in his sperm, because sperm contain so little cytoplasm. As a result, *N. granulosis* is transmitted solely by female hosts, not by the males.

So what happens when the protozoan ends up in a baby male shrimp? That would seem to be the end of the line. What's a protozoan to do? To bypass this dead end, *N. granulosis* takes over the sex-determining mechanism of the shrimp and converts the male into a female. That bit of genetic magic assures the protozoan's passage to future generations—though how it accomplishes this, no one knows.

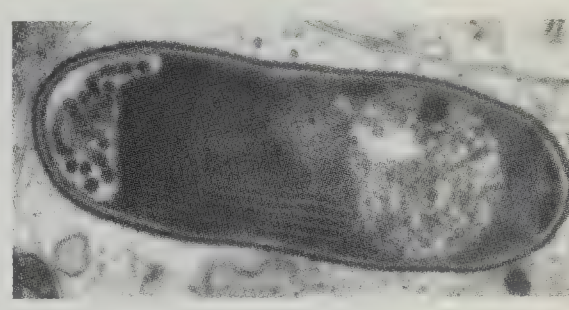
Naturally, if the protozoans were to become too common in host populations, they could drive the shrimp to extinction by causing a scarcity of males. Fortunately for the survival of both species, the protozoans are not transmitted to all the eggs of an infected mother; in the wild, in fact, they typically infect fewer than a fifth of the baby shrimp.

Parasites that manipulate the sex of their hosts are called reproductive parasites—and they are not as rare as one might like to think. Some, such as *N. granulosis,* convert males into females, but a widespread and diverse array of microorganisms simply kill the sons of their hosts; the daughters, which transmit the microorganisms, are allowed to live.

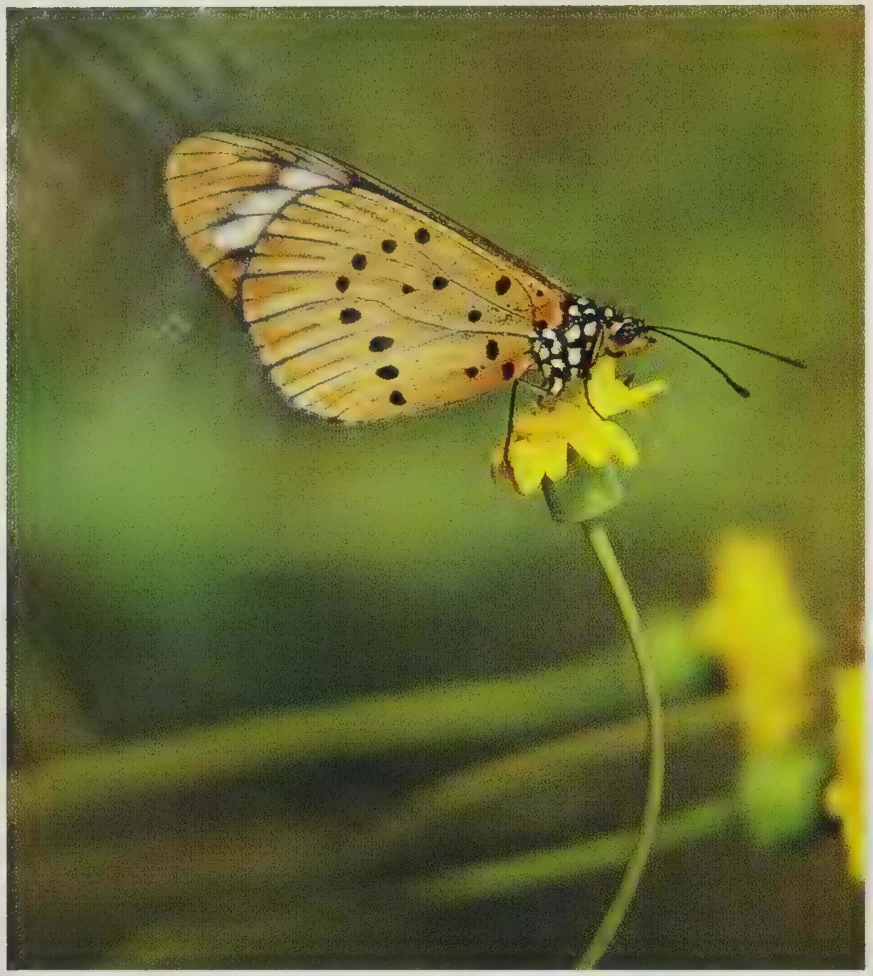
The protozoan *Amblyospora californica,* for instance, is transmitted through the eggs of infected female mosquitoes, but it kills the developing male larvae. Once again, that would seem to be a dead end for the protozoans in the males, but all is not lost. The protozoans in the males develop into specialized spores that cannot infect other mosquitoes but can infect small aquatic crustaceans called copepods. When a female copepod ingests the remains of a male mosquito larva killed by the protozoans, the copepod also ingests the spores. The protozoans then infect the female copepod and turn her ovaries into a "protozoan factory," generating the kind of spores that *can* infect mosquito larvae. When the mosquito larvae are filter feeding, they take in the spores from the water, and so complete the cycle. Thus the parasite has the best of both worlds: it exploits its female mosquitoes for transmission via eggs, and the male mosquitoes for infectious passage to new hosts. Pretty clever for an organism without a brain.

Other male-killers include various bacteria that make themselves at home in fruit flies, wasps, butterflies, and beetles. In those insects, though, the only way the microorganisms make it into the next generation of hosts is through the eggs of infected mothers. No sex-change operation on a male insect is possible; no suitable "third-party" species like the copepod is available to provide the parasites in males with an alternative host. For parasites that end up in a male, the options are limited. Killing the male insect has zero cost to the parasite, but what is the benefit?

In some cases it appears that killing off male hosts enhances the survival of the hosts' infected sisters. After all, without the males to compete with, the infected female insects have more resources for themselves. That alone, of course, doesn't help the parasites in the male insects. Unlike the *A. californica* protozoans, they gain nothing directly, because they die along with their hosts. They do gain indirectly, however, because the death of the male insects benefits the parasites' "family." All the parasites passed along by the infected mother insect are genetically identical to one another (that is, they are a clone). The parasites



Shrimp of the species Gammarus duebeni, *top, often harbor protozoans that are transmitted through the shrimp's eggs. In a step that ensures their own transmission, the protozoans can change a male host into a female. Bottom: The protozoan species in question,* Nosema granulosis.



Some populations of the white-barred Acraea, *above, are infected by* Wolbachia *bacteria that kill off most of the males. The female butterflies then assemble in courting areas, which attract the few remaining males.*

that happen to infect a daughter insect benefit from the additional resources available to her. So, by killing males the extended clone of parasites increases within host populations. For infected insect mothers, however, the infection is a disaster, because all of their sons are killed.

When male-killers become widespread, they can even affect the mating system of their hosts. Francis M. Jiggins, a biologist at the University of Cambridge, has detected male-killing microorganisms in high proportions of the individuals in some populations of African butterflies, and the highly skewed sex ratios that result lead to changes in the mating system. In *Acraea* butterflies males normally congregate at food plants, and matings take place there when the females arrive to lay their eggs. But in some populations of the white-barred *Acraea*, so many females are infected with male-killing bacteria (more than 95 percent in some cases) that males are extremely scarce. In those populations, females assemble in courting areas called leks to attract the few males that are flying about. These lucky males procure many matings, but there is still not enough sperm to go around, and many females remain uninseminated. Female leks are extremely rare in nature; in most species that form leks, it is the males that aggregate to attract the females. But under the pressure of male-killing bacteria, the white-barred *Acraea* appears to have evolved an unusual but adaptive mating system.

Biologists have just begun to document the diversity of male-killing bacteria in nature, and it is likely that a large percentage of invertebrate species play host to them. Vertebrates may also harbor male-killers, though none have yet been found. People need not worry, though: given the intense study of our own species, if we carried male-killing microorganisms, they would certainly have been discovered by now.

The white-barred *Acraea* is an extreme case; male-killers rarely infect a fraction of a population large enough to force a change in the mating system of a host species. Yet some biologists speculate that even a relatively small proportion of infected individuals (say, 5 percent) pushes the sex-determining genes of a host species to change in ways that enable it to escape or to suppress the male-killing effects. The cat-and-mouse game between male-killers and their hosts may be one of the motors contributing to the great diversity of sex-determining mechanisms that occur in nature.

The undisputed virtuosos of reproductive parasites are bacteria of the genus *Wolbachia*, which, like many of their brethren, are transmitted in the cytoplasm of eggs. These bacteria also infect across species boundaries, which has made them unusually widespread in invertebrates. *Wolbachia* bacteria infect many insects, arachnids (mites and spiders), crustaceans, and parasitic nematodes. At least 20 percent of all insect species harbor them, and the proportion could be as high as 70 percent—biologists are still trying to determine the number. Because most animal species are invertebrates, the abundance of *Wolbachia*'s hosts makes the genus among the most common parasitic bacteria on the planet. Analysis of its DNA indicates that the bacteria have lived in insects for at least 50 million years, and in invertebrates for at least 100 million. Only ten years ago *Wolbachia* was regarded as an obscure little group of bacteria, but the genus has come up in the world, at least in the eyes of biologists.

Its broad distribution is one of the major mysteries of *Wolbachia:* how can one genus of bacteria infect so many kinds of hosts? Some investigators speculate that species that are ecologically associated in some way (predators and prey, for instance, or competitors feeding on the same food resource) may occasionally exchange *Wolbachia*. But con-

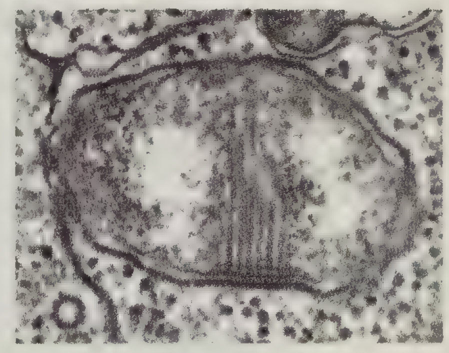
vincing evidence has not yet surfaced to back up the speculation.

Wolbachia bacteria are masters at manipulating the reproductive and cell biology of invertebrates. Like other reproductive parasites, some members of the genus kill the male insects they infect, whereas others turn males into sexually functioning females. Some even induce parthenogenesis in their hosts—a mode of reproduction in which eggs develop into females without fertilization, thereby dispensing with males and their sperm. Parasitic parthenogenesis has been noted in more than three dozen species of insects, mainly wasps. The bacteria accomplish this trick by manipulating the basic processes of the cell in such a way that the single set of chromosomes in the egg is duplicated, and the unfertilized egg develops into a female.

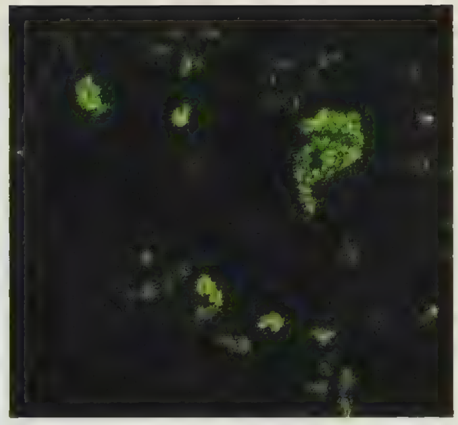
When the bacteria in parthenogenetic insects are killed with common antibiotics such as tetracycline, the insects usually revert to sexual reproduction. Sometimes, however, the insect species have been parthenogenetic for so long that when the *Wolbachia* bacteria are eliminated, the insects can no longer reproduce sexually. In the small parasitic wasp *Encarsia formosa,* antibiotics lead to the production of males, but the males cannot mate: the genes needed for male courtship have been lost. Other wasp species have similar stories to tell. In some, the females no longer respond to courtship; in others, the males no longer produce functional sperm. Given enough time, mutations accumulate in the genes for sexual characteristics, and the species can no longer revert to sexual reproduction. Their reproduction becomes completely dependent on the bacteria that live inside their cells.

Parasites that are passed on through the eggs of their host species face a potential dead end if they find themselves in a son of their former host.

But perhaps the most intriguing effect of *Wolbachia* is the ability of some strains to induce an incompatibility between host sperm and eggs, a process that may even implicate the microorganisms in the evolutionary divergence of insect species. The discovery of these capabilities has a long history. *Wolbachia* bacteria were



Above: A kind of bacterium living in this Encarsia *wasp causes it to reproduce parthenogenetically—that is, the wasp's eggs develop into females without the need for fertilization. Top right: The as-yet-unnamed bacterium, a relative of soil bacteria of the genus* Cytophaga.



A Brevipalpus phoenicis *mite, left, can be infected with the* Cytophaga*-like bacteria, above, which enable the mite to reproduce parthenogenetically. Other mite species carry* Wolbachia *bacteria that induce incompatibility between sperm and egg.*

first observed in the 1920s, when the pathologists Arthur Hertig and S. Burt Wolbach, working at Harvard Medical School, found them inside the eggs of *Culex* mosquitoes. Hertig later named the bacterial genus in honor of his colleague and mentor. In the 1950s the German biologist Hannes Laven discovered that when males from some strains of the mosquito *C. pipiens* were crossed with females of another strain, the offspring died as embryos. Laven subsequently showed that the effect was inherited through the mother's lineage. As he viewed it, the cytoplasm in the eggs of certain strains of insects was incompatible with the sperm from certain other strains. Laven was apparently unaware, however, that bacteria had earlier been discovered in the eggs of the insects.

It wasn't until the early 1970s that two other investigators, Janice H. Yen and A. Ralph Barr of the University of California, Los Angeles, made the connection. They showed that Laven's "cytoplasmic incompatibility" was caused by the bacteria. Antibiotic treatments that eliminated the bacteria also changed the compatibility relationships between males and females.

The basic pattern is that eggs from uninfected females are incompatible with sperm from infected males. The *Wolbachia* present in the testes of males biochemically "encrypt" the developing sperm, probably by altering proteins that bind to the sperm DNA. The same strain of *Wolbachia* must then be present in the egg to "decode" the encrypted sperm. Otherwise the chromosomes from the sperm are not properly processed in the fertilized egg, and the embryo dies. The actual mechanisms are still a mystery, but it is already clear to investigators that there are many different kinds of *Wolbachia,* which differ in their encryption systems.

The diversity of the encryption mechanisms raises the possibility that *Wolbachia* could play a role in the evolution of new insect species. If different populations of a species, or closely related species, are infected with different strains of *Wolbachia,* the bacteria could prevent the insects' gene pools from mixing. Just such a circumstance may have arisen in jewel wasps, a genus *(Nasonia)* of small parasitic wasps that kill fly pupae. There are three closely related species of jewel wasps, but each is infected with its own distinct *Wolbachia.* The bacteria render any matings between the different wasp species incompatible, thereby preventing the development of hybrids.

Biologists have also discovered that *Wolbachia* plays an essential developmental role in some host species. For example, if *Wolbachia* bacteria in the wasp *Asobara tabida* are eliminated with antibiotics, the female wasps fail to develop ovaries and so become sterile. Filarial nematodes—parasitic "worms" that cause such diseases as river blindness and elephantiasis in people and heartworm in dogs—also need the bacteria if their embryos are to develop properly. Antibiotic treatment of adult worms kills the embryos, rendering the adults sterile. This discovery has increased interest in the possibility that nematode diseases can be controlled with antibiotics [*see "The Worm and the Parasite," by T. V. Rajan, page 32*].

To study the details of *Wolbachia*'s capabilities, biologists have experimentally transferred the bacteria from one insect species to another. The method is similar to the microinjection techniques developed for in vitro fertilization: a needle containing the bacteria from one insect is injected into the egg of a different, uninfected species. Not surprisingly, perhaps, the "foreign" *Wolbachia* bacteria can have different effects in their new hosts. For example, in the adzuki bean borer moth *(Ostrinia scapulalis), Wolbachia* turns a male host into a female. When the same bacteria are injected into the common flour moth *Ephestia kuehniella,* however, they simply kill the males.

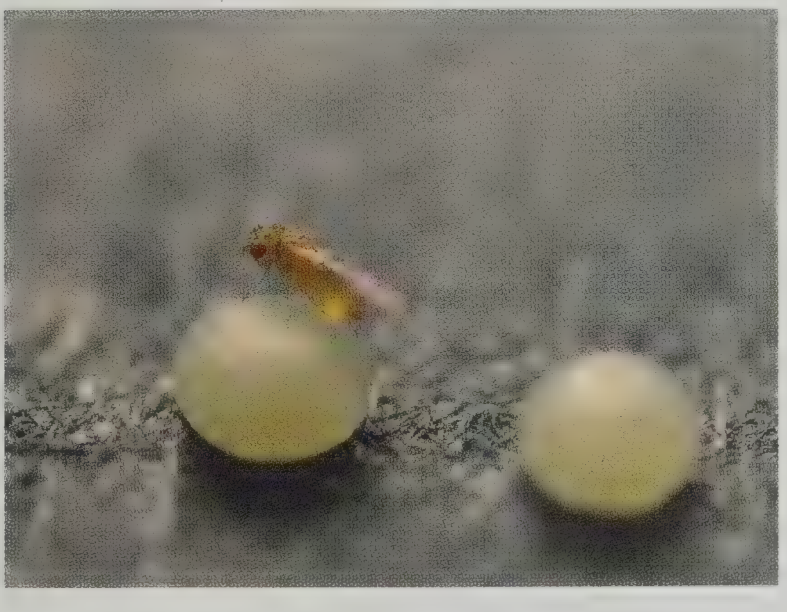
Alerted to the newly recognized importance of *Wolbachia* in manipulating invertebrate reproduction, investigators are now discovering an en-

Fifty million years from now, Wolbachia *bacteria may, like the mitochondria before them, have evolved into a new kind of cell organelle.*

tire pantheon of sex-manipulating microorganisms that are transmitted from females to their offspring through eggs. A recent finding is a relative (as yet unnamed) of soil bacteria in the genus *Cytophaga.* Biologists have shown that the unnamed bacterium induces parthenogenesis in hosts as varied as wasps and mites, and is likely to be widespread.

Others await discovery. The genus *Rickettsia,* which is a member of the same family as *Wolbachia,* includes a number of disease-causing bacteria spread by arthropods, such as the microorganisms responsible for Rocky Mountain spotted fever and typhus. Recently, *Rickettsia* bacteria that are transmitted through eggs and cause male-killing have been identified. I anticipate that once additional discoveries are made, it will be clear that most members of the genus are engaged in distorting sex in arthropods, and that causing disease in vertebrates is a relatively uncommon trait. The widespread occurrence of reproductive parasites illustrates a basic principle: whenever a microorganism is inherited through the eggs of its host, it will be selected for its capacity to manipulate the host's reproduction in ways that enhance the microorganism's transmission.

An even more remarkable story than that of *Wolbachia* and other reproductive parasites belongs to the "microbes" present in nearly all plants and animals—the mitochondria. Flourishing in the cytoplasm of nearly all nucleated cells, mitochondria are specialized organelles, with their own DNA. They are the cell's power stations, generating energy for cellular metabolism. There is now overwhelming evidence that mitochondria evolved from a symbiotic bacterium during the early evolution of nucleated cells. In fact, on the basis of similarities in their DNA, biologists now think mitochondria and *Wolbachia* may be distant relatives.



The small parasitic wasp Trichogramma kaykai *deposits its eggs within the eggs of butterflies. Inside the ovaries of this wasp are* Wolbachia *bacteria that induce parthenogenetic development of the wasp eggs.*

Like *Wolbachia,* mitochondria are inherited through the cytoplasm, and therefore from mothers but not from fathers. And, like *Wolbachia,* mitochondria that skew the sex ratio of their "host" organisms toward females can be favored by natural selection. Biologists have demonstrated that in many plants, such as corn and rye, mitochondrial variants cause an abortion of the male parts of the plant, the pollen-producing anthers. The effect is known as cytoplasmic male sterility, and it leads to an increased production of seeds, which transmit the mitochondria. A contest ensues: plant genes evolve that suppress the renegade mitochondria, and new mitochondrial variants arise that can escape the new control.

As far as anyone knows, animal mitochondria do not play such games. The reason may be simply that animal mitochondria have much smaller genomes than their counterparts in plants, and therefore may not be able to draw from as rich a grab bag of genetic trickery. Fortunately for animals and plants, most of the time mitochondria are quite well behaved.

The comparison with mitochondria raises one final, tantalizing question about bacteria of the genus *Wolbachia.* Given their ubiquity, their adopted homes within the cells of other organisms, and their heritability through the eggs of their hosts, why haven't they evolved into organelles like the mitochondria before them? Perhaps it's only a matter of time before they do. If bacteriologists take a peek in, say, 50 million years, they might well find that *Wolbachia* bacteria have been tamed by some invertebrate group and have evolved into a new kind of cell organelle. What service that organelle might perform is anyone's guess. □

Tuff Crowd

Formations of volcanic rock dominate a landscape in southeastern Arizona.

By Robert H. Mohlenbrock

About 27 million years ago, in what is now the southeastern corner of Arizona, a volcano spewed out vast amounts of hot ash and pumice that fused into a 2,000-foot layer of rock known as rhyolitic tuff. Subsequent erosion has transformed the landscape into an incomparable collection of spires, chimneys, and balanced rocks. Located about thirty-five miles southeast of Willcox, Arizona, Chiricahua National Monument was established in 1924 to protect these formations. The botanist and author Janice Emily Bowers has described them imaginatively yet accurately: "chess pieces—pawns and castles, knights and bishops, kings and queens, all crowded together at one end of the chessboard."

When my wife Beverly and I pulled up to the entrance station of the monument, a cheerful and enthusiastic ranger asked if we had ever visited before. "About thirty years ago," I replied. "Well, nothing has changed much," the ranger told us. And she was right. The stone pillars and balanced rocks looked the same, of course, but that wasn't all. A raccoon-like coati scurried across the road and into the adjacent woodland, just as one did thirty years before. A Mexican jay was drinking from a catch basin at a public water fountain, just as Beverly remembered one doing three decades ago. And the thick-billed parrot, the only parrot whose native range once extended north of the Mexican border, was still nowhere to be seen (the species was extirpated from this locale in 1922, and predators have foiled attempts to reintroduce it). But I did notice that the trees lining the road had grown somewhat taller.

We followed the main park road, which winds about eight miles through Bonita Canyon and on up to Massai Point. The canyon is forested mainly with pines and junipers, but other trees grow along the streambed that the road follows for much of the way. (Water flows through the stream most predictably during the months

Rock formations and trees, viewed west from Massai Point

For visitor information, contact:
Chiricahua National Monument
13063 East Bonita Canyon Road
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(520) 824-3560
www.nps.gov/chir/

of July and August, when a shift in wind direction brings "monsoon" rains.) At the end of the drive we got a superb view of the rocks and pinnacles below.

On the way back we stopped in Bonita Canyon to hike the Natural Bridge Trail, which heads north for half a mile or so, then turns westward out of the canyon and enters an upland woods. About 120 acres here have been designated Picket Park. The ground cover, particularly on ridges that get the full brunt of the sun, is mostly chaparral, a community of drought-tolerant plants, often with leathery leaves that inhibit evaporation. Oak woodland predominates below the ridges, on rough, south-facing slopes where heavy exposure to the sun combines with steep terrain broken by columns, cliffs, and ledges.

Continuing our hike through Picket Park, we reached a zone where mixed conifer forest, with stands of rare Apache pine and Chihuahua pine, grows amid the rock formations. Finally we came to a pine and oak woodland nestled in a narrow, steep-walled canyon. At the canyon bottom is an impressive stand of Arizona cypress. From there the trail would have taken us south to a rock formation called Natural Bridge, but we decided it was time to turn back.

First-time visitors should be sure to follow the trail to Heart of Rocks for a close-up view of some of Chiricahua National Monument's most popular rock formations, with names such as Duck on a Rock and Punch and Judy [*see photograph on this page*]. Big Balanced Rock is perhaps the most famous (and most photographed) of all.

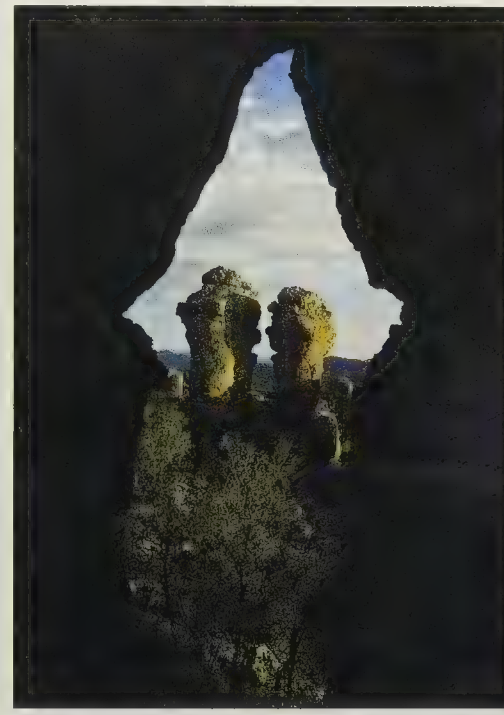
HABITATS

Streamside forest Along the streams and washes are Arizona sycamore, Fremont cottonwood, Arizona walnut, velvet ash, and Arizona cypress. Flowering herbs and shrubs include horsetail, seep willow, desert broom, threadleaf ragwort, desert willow, hummingbird trumpet, chokecherry, Apache plume, western white honeysuckle, mutton grass, and skunk-bush.

Chaparral Principal woody plants are alligator juniper, Emory oak, Mexican pinyon pine, Arizona cypress, and the shrubby Toumey oak, deerbrush, and mountain mahogany. Wildflowers, grasses, and flowering shrubs include woolly Indian paintbrush, bristlehead, rabbitbrush, turpentine bush, yellow hawkweed, threenerve goldenrod, dwarf desert peony, American threefold, pinyon ricegrass, century plant, Palmer's agave, and small palmleaf thoroughwort.

Oak woodland The primary woody plants are dwarfed and gnarly and include Toumey oak, silverleaf oak, Arizona white oak, netleaf oak, Emory oak, Mexican pinyon pine, and alligator juniper. Wildflowers and shrubs include longstalk greenthread (whose flowers resemble a dandelion head), Wright's beebrush, antelope sage, evergreen sumac, sotol, century plant, bear grass, ocotillo, cliff fendlerbush, turpentine bush, evergreen rock fern, and beggartick three-awn (a grass).

Mixed conifer forest Ponderosa pine, Douglas fir, and Arizona cypress are the dominant trees above layers of Apache pine, Chihuahua pine, pinyon pine, silverleaf oak, Emory oak, Arizona white oak, alligator juniper, Arizona madrone, and pointleaf manzanita. Among the wildflowers, flowering shrubs, and grasses are Chiricahua Mountain columbine, desert



Punch and Judy

blazingstar, Santa Rita Mountain aster, plains blackfoot, southwestern cosmos, purple locoweed, Alpine false spring parsley, false Solomon's seal, showy goldeneye, cardinal catchfly, Huachuca Mountain geranium, satin bunchgrass, Wright's silktassel, and bear grass.

Pine and oak woodland usually occurs in canyon bottoms, which provide enough moisture for the growth of Arizona cypress, Arizona white oak, alligator juniper, netleaf oak, and silverleaf oak. Wildflowers and flowering shrubs include antelope horns, pineneedle beardtongue, dwarf false pennyroyal, Chihuahuan brickellbush, Missouri goldenrod, roving sailor, cliff fendlerbush, mutton grass, and Ross' sedge.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

Tightening Our Kuiper Belt

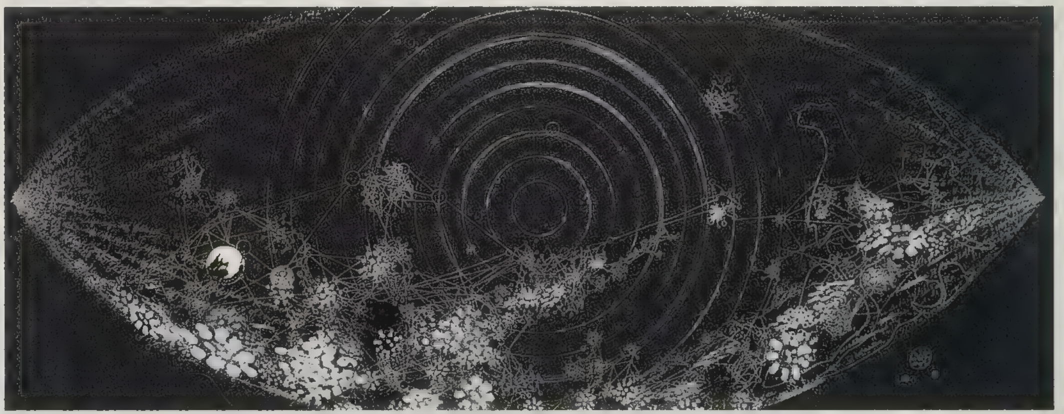
From the edge of the solar system come hints of a disrupted youth.

By Charles Liu

More and more often, some new astronomical discovery is thrusting Pluto and its home, the Kuiper Belt, into the public eye. Most of the attention focuses on Pluto's status as one of our solar system's major planets. Should it retain that status, even though astronomers know Pluto really is just a ball of ice and rock, smaller than our Moon?

A few months ago the flames were fanned again, when Michael E. Brown and Chadwick A. Trujillo, both astronomers at Caltech, announced the discovery of a large new Kuiper Belt object (or KBO) that they dubbed Quaoar (after the creation force of the Tonga tribe who lived in the Los Angeles area). No one was calling Quaoar a major planet; it's only 800 miles wide. Yet Pluto—about 1,400 miles in diameter—isn't that much bigger than Quaoar, and Quaoar's orbit looks much more like the orbits of the other eight major planets than Pluto's does. Pluto-bashers everywhere hailed Quaoar as further proof that the runt of the traditional nine planets should be reclassified as just another KBO, albeit a large one.

But all the hoopla missed the scientific point. For many of us astronomers, it's not Pluto, Quaoar, or any other individual KBO that matters; it's the Kuiper Belt itself that counts. And if you take the Pluto-Quaoar episode as an occasion for a closer look at the Kuiper Belt, you get into some pretty intriguing scientific questions. For example, R. Lynne Allen of the University of British Columbia in Vancouver and her collaborators recently published findings that, though useless to the argument about what to call Pluto, suggest that the Kuiper Belt is a surprisingly sharp edge cinching our solar system five billion miles out from the Sun, and that it holds some clues to our solar system's early history.



Eva Lee, *Eyesites,* 2000

Named after the Dutch American astronomer Gerard Kuiper, one of the first people to posit its existence, the Kuiper Belt is a doughnut-shaped zone of space, populated by comets and comet-like bodies, which lies beyond the orbit of Neptune. KBOs are small—most are less than 100 miles across—and made up almost entirely of ice and rock. They're remnants of the solar system's early history, relatively unaltered by four and a half billion years of stellar and planetary evolution.

Someday astronomers will get the chance to study KBOs up close, and the objects will provide an unparalleled glimpse into the chemical and physical conditions of the early solar system. But the scientific value of the Kuiper Belt as a whole is even greater than the sum of the information in every icy dirt ball. The reason is that in the past decade or so, astronomers have discovered disks of dusty gas as large as 100 billion miles in diameter orbiting a number of stars much younger than, but otherwise quite similar to, our Sun. According to current astrophysical models, planets originate in these disks, and our solar system represents one possible outcome of the evolution of such a disk. The Kuiper Belt is probably what remains of the Sun's original disk, so its shape, size, and thickness serve as critical benchmarks for understanding how planetary systems form, grow, and age.

Neptune's orbit, a nearly circular ellipse some three billion miles away from the Sun, traces the Kuiper Belt's inner edge. The belt's outer edge is far less certain, though. Of more than 600 KBOs discovered to date, none of those with nearly circular orbits is more than roughly five billion miles from the Sun. That suggests the Kuiper Belt's outer boundary could well lie there. But the outer boundaries of the disks orbiting the younger stars I mentioned are as much as

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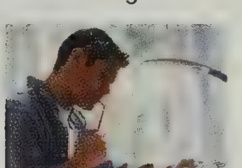

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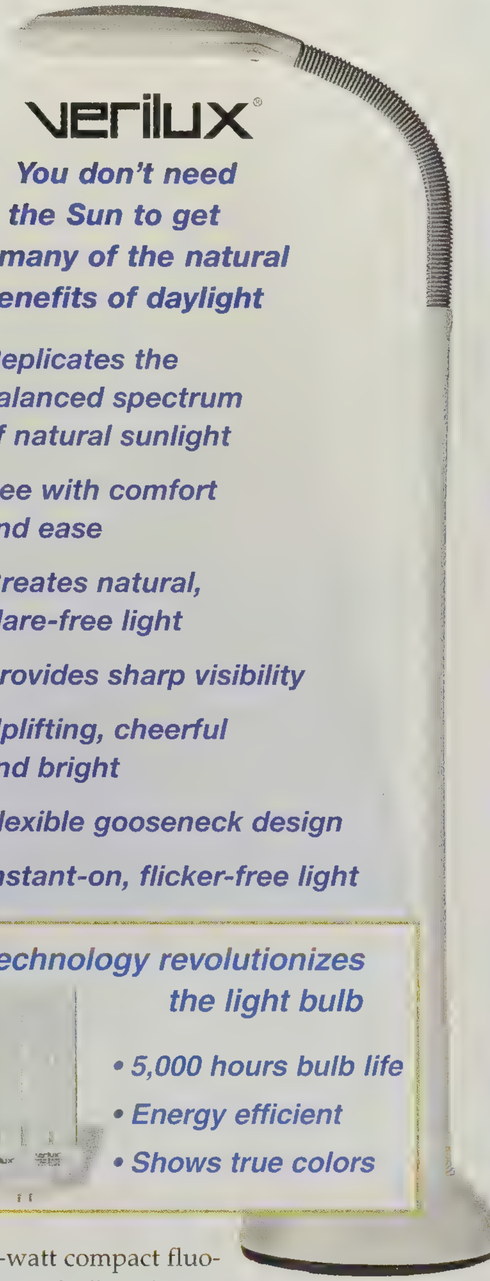

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twenty times farther away from their central stars. If the Kuiper Belt is what's left of such a disk around our Sun, why is it so small?

To resolve this discrepancy, astronomers have proposed a composite shape for the Kuiper Belt, with an inner part that bulges like a bagel, and an outer part that's thin like a dinner plate. According to that model, the belt extends a long way out, but the hypothetical KBOs that would allegedly make up the outer part of the belt haven't been discovered because they're confined to a narrow band—about the width of an outstretched pinkie—across the sky.

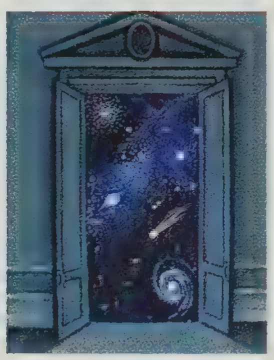
Enter Lynne Allen. To test the predictions of the model, she trained the four-meter telescope at the Kitt Peak National Observatory in Arizona on portions of the band of sky where the model suggested she would find the outer Kuiper Belt. Sure enough, she found dozens of new KBOs there to be sure, but none of them were more than five billion miles away. By Allen's calculations, the observations strongly suggest that the KBO distribution has a sharp boundary at that distance, and that a thin outer Kuiper Belt simply does not exist.

So the question remains: why is the Sun's Kuiper Belt so much smaller than the disks of other stars? One possibility is that, billions of years ago, our solar system suffered a major disturbance—perhaps a near-collision with a passing star—that chopped the outer regions off the Sun's circumstellar disk. If so, such a cropping would have directly affected the development of our entire planetary system. For one thing, a larger disk might have caused many more comet collisions early in Earth's history. If the passing-star scenario can be confirmed, it may show that the development of life on Earth was linked to a chance but crucial event in the history of the Kuiper Belt.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN FEBRUARY

By Joe Rao



Swift **Mercury** shines low along the east-southeastern horizon about an hour before sunrise in the first week of February. The planet, as bright as magnitude −0.1, reaches its greatest western elongation from the Sun on the 4th, 25 degrees from the Sun's glare. For the rest of the month Mercury falls back toward the Sun and, as early as midmonth, is hopelessly lost in the morning twilight.

Brilliant **Venus** graces the dawn low in the southeast, though not quite so brightly as it did in January. The planet fades from magnitude −4.3 to −4.1 and sinks about 5 degrees lower into the sunrise. It has also entered its uninteresting season for telescopic observers; it looks like a small, featureless, gibbous Moon for the rest of the year. But Venus is still immensely brighter than any other point of light. Early risers in the first half of the month can enjoy watching the "teapot" of Sagittarius gliding below Venus in the starry background, then moving above and to the right of the planet as the weeks go by. On the morning of the 27th a waning crescent Moon appears on the southeastern horizon, well below and to the right of Venus.

Mars rises between 2:30 and 3:00 A.M. local time throughout the month, and is well up in the south-southeast by dawn. Shining at magnitude 1.3, the planet passes 5 degrees north of the first-magnitude star Antares on February 1, as it moves through the constellation Ophiuchus. Although Mars remains rather inconspicuous, its luminosity continually increases as the Earth's smaller, faster orbit brings the two planets closer. Mars reaches opposition in August, when it will be just 34,646,418 miles from the Earth, but in mid-February it's still 154 million miles away. Seen through a telescope, it presents a minute disk. A fat crescent Moon will be hovering well below and a bit to the left of Mars on the morning of the 25th.

Silvery white **Jupiter**, low in the east this month as the sky darkens at sundown, dazzles the eye at magnitude −2.6. Jupiter is at opposition to the Sun on February 2; it rises at sunset, stands highest in the south at midnight, and sets at dawn. At dusk on the 15th, Jupiter climbs the east-northeastern sky alongside the Moon, which is just one day from full.

Saturn, in the eastern part of the constellation Taurus, is high toward the south in the early evening hours. It sets in the west at around 4 A.M. at the beginning of the month and about two hours earlier by month's end. At magnitude −0.2, Saturn carries on its grand show for viewers with telescopes, as the great ring system continues to tilt steeply toward Earth. Late on the night of February 11, the Moon appears to pass less than 3 degrees to the north of Saturn.

The **Moon** is new on February 1 at 5:48 A.M. It reaches first quarter on the 9th at 6:11 A.M., full on the 16th at 6:51 P.M., and last quarter on the 23rd at 11:46 A.M.

Unless otherwise noted, all times are given in Eastern Standard Time.

REVIEW

The Curious Energy of the Void

Dark energy is making the universe bigger and bigger, faster and faster.

By Donald Goldsmith

Andrea Way, *The Holy Tree*, 1997

The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos
by Robert P. Kirshner
Princeton University Press, 2002; $29.95

In February 1998 new observations of exploding stars in distant galaxies stood the world of cosmology on its ear. The expansion of the universe, far from slowing down, as earlier theories had implied it should, turned out to be speeding up. Objects in the universe are moving apart from one another at progressively greater speeds. The new findings foretell a future in which the cosmos becomes an unimaginably vast, cold, dead, and barren expanse of near-nothingness.

How did astronomers reach such a startling conclusion?

In 1916 Einstein, shortly after completing the formulation of his theory of general relativity, discovered that the solutions to a key equation within the theory implied that the universe must always be either expanding or contracting. Einstein's pencil-and-paper discovery took him by surprise, because astronomers of the era had no evidence to suggest that the universe either expands or contracts. To fix what he then took to be an error, he restated his key equation with an additional, constant term—which quickly became known as the cosmological constant. If the constant had precisely the right value, Einstein wrote in 1917, the universe could exist in a state of perfect, static balance.

But the Russian mathematician Alexander Friedmann soon demonstrated that such a static universe must be balanced, as it were, on a knife edge: the slightest tremor would topple it over in one direction or the other, into a state of either expansion or contraction. Another, even more serious objection to Einstein's solution appeared in 1929, when Edwin Hubble discovered that the cosmos is indeed expanding. On distance scales as large as the ones between clusters of galaxies, all objects are moving away from all other objects at speeds that increase in proportion to the distances between them. (Cosmologists imagine the expanding universe most simply as the three-dimensional analogue of the skin of a balloon. As the balloon expands, every point on the skin of the balloon moves away from all others, yet no one point is motionless.) Einstein soon pronounced the cosmological constant a dead letter, calling it his "greatest blunder."

The results announced in 1998 effectively resurrected Einstein's "blunder." Those observations included two kinds of measurements: first, the distances to certain kinds of supernovas, or exploding stars, that astronomers discovered in distant galaxies; and second, the speeds with

which those galaxies are receding from us. But when astronomers tried to describe the relation between those distances and speeds, they found they had to restore Einstein's full equation from 1917, including a nonzero cosmological constant.

The value that the 1998 observations imply for the cosmological constant is not equal to the value Einstein adopted to keep the universe static—after all, the two kinds of universe could hardly be more different. But the fact that the recent observations require a nonzero value for the constant carries a tremendous implication: Every cubic centimeter of what seems to be empty space instead teems with hidden energy, which astronomers now call dark energy. As the universe expands from its origins in the big bang, more space continuously comes into being, and so the total amount of dark energy also increases proportionately. The ever-growing amount of dark energy progressively accelerates the universal expansion. Although gravity acts in the opposite sense, tending to slow the expansion because all matter in the universe attracts all other matter, the expansionist tendency of the dark energy has now become dominant. The cosmos has entered a phase of accelerating expansion.

Such a striking result should be accepted with caution. Astronomers have spent years determining the distances and velocities of remote galaxies. Although the galaxies' velocities can be found relatively easily by measuring the shift in the colors of their light, finding their distances has proved much more difficult. In fact, astronomers could make only fairly crude estimates of the distance to any faraway galaxy—until they identified a marvelous type of exploding star called a type Ia supernova (or SN Ia for short).

Like the light from other exploding stars, the apparent brightness of a type Ia supernova grows for a few days, reaches a peak, and then fades away

over several months' time. But unlike other supernovas, all type Ia supernovas at their brightest generate nearly the same amount of energy per second. Thus they furnish astronomers with "standard candles," objects that are almost identical in their intrinsic luminosities. If observers can identify two such supernovas in different galaxies, measuring how bright they appear at their peak outputs is enough to calculate their relative distances. For example, if one SN Ia appears four times as bright as another, the fainter supernova must be twice as distant as the brighter one (by simple geometry, the brightness decreases with the square of the distance).

This method works only if astronomers can identify exploding stars as members of the SN Ia class and can control for the fact that, even within that class, some variation does exist. Beginning in 1995, two competing groups of astronomers have been obtaining brightness measurements of type Ia supernovas to analyze the expansion of the universe.

At first the findings of the two groups contradicted each other, leading to suspicions within each group that the data from the other group were flawed. The cause of science could hardly ask for more favorable circumstances. There is probably no better way to check the accuracy of one group's results than to pit that group against another, particularly if the second group suspects the first of promulgating grievous errors. In this case, happily, the results converged. As improved techniques began to eliminate the differences in the observational data, both groups concluded that their measurements could be explained only if the universe has a nonzero cosmological constant.

Robert Kirshner, a supernova expert at Harvard, has written an excellent insider's account of the race to discover the fate of the cosmos. In *The Extravagant Universe* Kirshner skillfully weaves the details of his career—which brought him to the leadership of one of the SN Ia observer groups—into the larger cosmic story. Along the way he pauses to describe a host of astronomical phenomena, from the life cycles of stars to the effect of the cosmological constant on the universe's expansion.

Kirshner shows an impressively deft touch with complex explanations, and he doesn't hesitate to bridge gaps in the reader's knowledge with an apt metaphor. For example, one of the constraints on the synthesis of every element heavier than helium is that no atomic nucleus only slightly heavier than helium is stable in nature. As a result, no natural process can make the heavier elements by adding protons or neutrons one by one to a helium nucleus. How then do stars succeed in doing so? As Kirshner puts it, they "skip across that gap, as improbably as crossing a stream by stepping on a salmon, to fuse three helium nuclei into a single carbon nucleus." The image may not exactly explain the phenomenon, but it remains satisfyingly in mind.

The Extravagant Universe presents an intriguing history of how supernova observers discovered the accelerating universe. But the full story of the acceleration has another crucial aspect. In 1999 and 2000, radio astronomers announced that entirely independent observations—made by radio telescopes studying the faint glow from the early universe known as the cosmic microwave background (CMB)—likewise imply a nonzero cosmological constant. Hence they, too, imply an accelerating universe.

The new data are arguably even more fundamental than the observations of distant supernovas. Not only do they reveal an accelerating universe; they also record how the amount of radiation generated by the universe in the earliest years of its expansion varies in different directions in space. By measuring those variations astronomers can determine how strongly space is curved. The amount of curvature depends on the sum of

PHOTOGRAPHY & ART

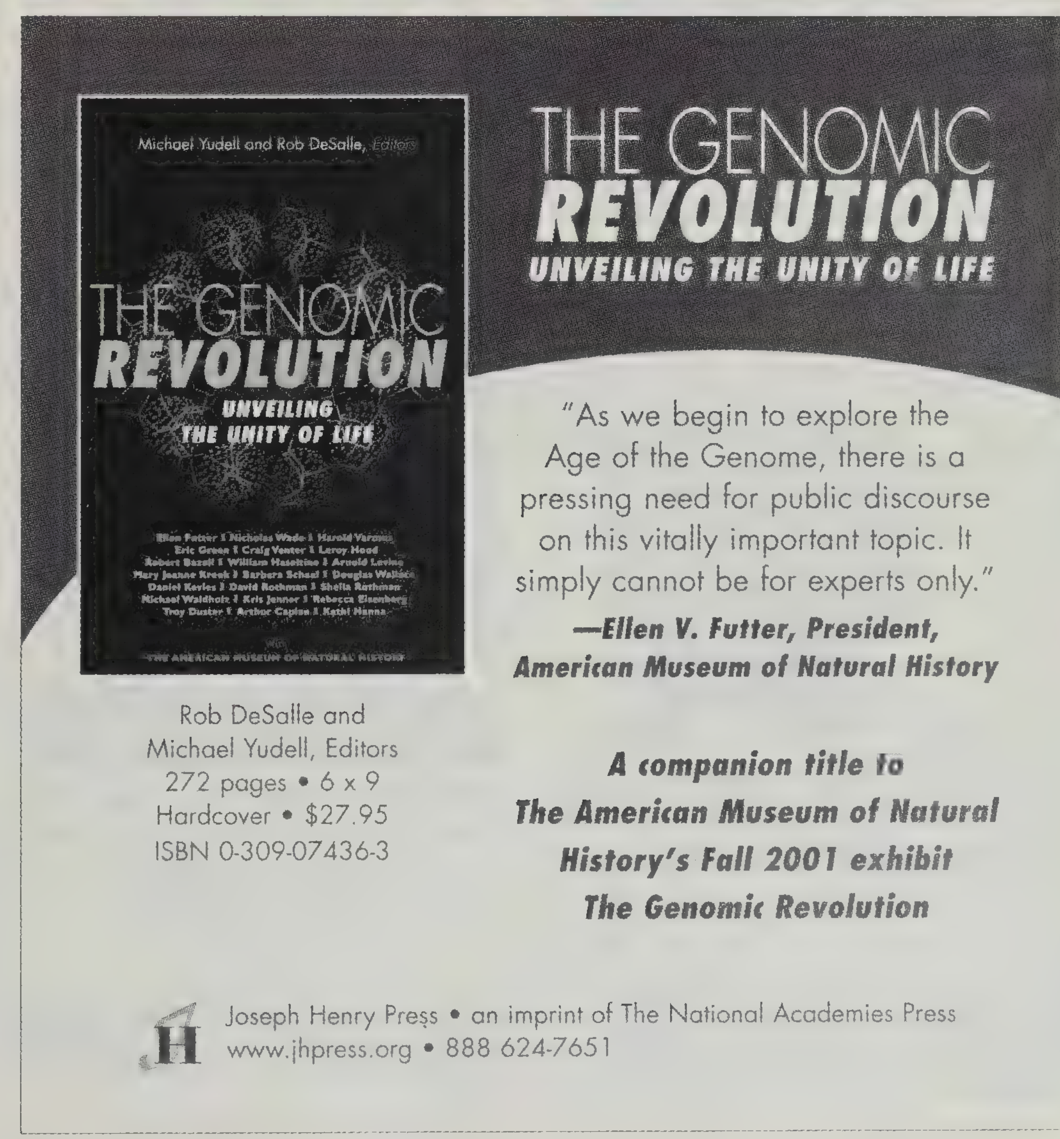
Dodo: A Brief History, *by Errol Fuller (Universe Publishing, 2002; $22.50)*
No extinct animal is less extinct as a cultural icon than the dodo. Missing from the Earth since the late seventeenth century, the flightless bird from Mauritius lives on in historical accounts, literary sources, and popular myths, many gathered together in Fuller's sumptuous book. They fill in admirably for the dearth of evidence about the real thing.

the dark energy and the energy locked up in all the matter in the universe—the second of which, at least in theory, is equivalent to the energy given by Einstein's famous formula $E = mc^2$. Hence measuring the variations in the cosmic microwave background can help determine the amount of dark energy in the universe.

The supernova observations, in contrast, give the difference between the amount of dark energy, which accelerates the expansion of the universe, and the amount of matter, whose mutual gravitational attraction slows it down. In the best of all worlds, combining the results from the radio and the supernova observations will give an accurate measurement not only of the amount of dark energy but also of the amount of matter—most of which, as it happens, is made up of a completely unknown form called dark matter.

Kirshner deals only in passing with the CMB observations, yet those data are highly relevant to the story because they have sharply increased astronomers' confidence that the cosmic expansion is accelerating. A further exploration of that story, however, would require another book. *The Extravagant Universe* delivers the promise of its subtitle extremely well, and should serve as the definitive insider's story of how Kirshner led his motley group of astronomers to glory in their search to find the fate of the universe. Nothing now remains for cosmology—except to explain why the universe has turned out the way it has. That's a big challenge for our new century, but, given the remarkable successes so far, it may prove to be well within our grasp.

Donald Goldsmith, an astronomer and science writer, won the 1995 Annenberg prize, given by the American Astronomical Society for outstanding contributions in popularizing astronomy. His most recent books on cosmology are Einstein's Greatest Blunder? *(Harvard University Press) and* The Runaway Universe *(Perseus Books).*

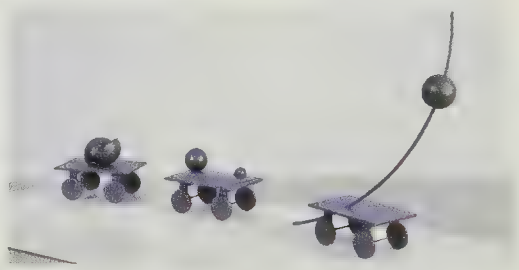


Scaling Down

By Robert Anderson

It's a pretty safe bet that you're never going to travel more than a few thousand miles from home—how could you, without becoming an astronaut and leaving the Earth itself? So how can you hope to get an intuitive grasp of the size of the solar system? Given the distances, measured in millions and billions of miles, my guess is it's nearly impossible. You might as well try to conjure a visceral sense of geologic time—surely a quixotic exercise, when you think about the seconds ticking by as life evolves from jellyfish to human.

But still, you can try. And if you have any interest in astronomy, the wow factor is well worth the effort of thinking about how the solar system would scale down to a more manageable size. Now the Exploratorium in San Francisco has introduced a Web site (www.exploratorium.edu/ronh/solar_system/index.html) that will blast you off to a great start. You type in how big you want your model sun to be, and the site does the rest, calculating the size of each planet and its distance from the Sun. I typed in 9.5 inches for my model, the diameter of a basketball, and was surprised to



Richard E. Prince, *The Wand'ring Planets,* 2002

learn that the Earth would be the size of a peppercorn, eighty-five feet from the Sun, and Pluto would be almost two-thirds of a mile away. The Web site also calculates such things as the distance to Alpha Centauri—after the Sun, the nearest bright star. On my chosen scale its distance would be 4,351 miles. Much beyond that, though, and the model quickly becomes almost as unmeaningfully large as the real thing.

If you want to find out about large-scale solar system models, check out the links at the bottom of the Exploratorium Web page. My favorite, the most ambitious project in North America but still a work in progress (unless more funding can be found), has been laid out across 200 miles of central Kansas (www.fhsu.edu/solarsystem/). The planets are roughly aligned along Interstate 70, running east from the city of Hays, where the enormous dome of the Sternberg Museum of Natural History stands in for the Sun. A project much closer to completion can be found in northern Maine (www.umpi.maine.edu/info/nmms/solar/index.htm), where three-dimensional scale models of the planets adorn forty miles of U.S. Route 1, from Presque Isle to Houlton.

Robert Anderson is a freelance science writer living in Los Angeles.

UNIVERSE

(Continued from page 29)

ment number 95 is americium; number 98 is californium; number 103 is lawrencium, for Ernest O. Lawrence, the American physicist who invented the first particle accelerator.

Ever-larger accelerators reach ever-higher energies, probing the fast-receding boundary between what is known and what is unknown about the universe. The big bang theory of cosmology asserts that the universe was once a very small and very hot soup of energetic subatomic particles. With a super-duper particle smasher, physicists might be able to simulate the earliest moments of the cosmos. In the 1980s, when U.S. physicists proposed just such an accelerator (eventually dubbed the Superconducting Super Collider), Congress was ready to fund it. Plans were drawn up. Construction began. A circular tunnel fifty-four miles around was dug in Texas. Physicists were eager to peer across the next cosmic frontier. But in 1993, when cost overruns looked intractable, a fiscally frustrated Congress permanently withdrew funds for the $11 billion project. It probably never occurred to our elected representatives that by canceling the Super Collider they surrendered the U.S. primacy in experimental particle physics.

If you want to see the next frontier, hop a plane to Europe, which seized the opportunity to build the world's largest particle accelerator and stake a claim of its own on the landscape of cosmic knowledge. Known as the Large Hadron Collider, the accelerator will be run by the European Laboratory for Particle Physics (better known by an acronym that no longer fits its name: CERN). Although some American physicists are collaborators, the U.S. as a nation will watch the effort from the sidelines.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

EXPLORER GUIDE

AstroBulletin Showcases Cutting-Edge Research at the South Pole

RANDY LANDSBERG

Vivian Trakinski and Jason Lelchuk celebrate their arrival at the South Pole, which is designated by the marker in the foreground.

For decades, cosmology, the study of the origin and evolution of the universe, garnered little support within the scientific community because few believed there was enough direct evidence to support such inquiry. Today, however, it is generally agreed among both astronomers and physicists that the universe was created some 10 to 20 billion years ago in an explosion dubbed the "Big Bang."

But how can we know about an event that took place so long ago? The cosmic microwave background (CMB)—called a "background" because it is detectable from every direction across the sky—is a whisper of microwave radiation, a vast curtain of energy. By identifying and observing the CMB, scientists are able to draw conclusions about the distant history of our universe, as far back as its creation. The pervasiveness and uniformity of the radiation throughout the universe suggests that it remains from a time when the universe was significantly hotter and denser than it is now, supporting the notion of a Big Bang–type origin.

Scientists from the University of Chicago's Center for Astrophysical Research in Antarctica (CARA) are studying the CMB at the Amundsen-Scott South Pole Station. Taking advantage of Antarctica's long winters, dry conditions, and endless sky, they are making what are arguably the most detailed measurements ever of the CMB, thereby building a body of data that will increase our understanding of the origin and evolution of the universe.

In December 2001, Vivian Trakinski and Jason Lelchuk, members of the Museum's Science Bulletins production team, journeyed to the South Pole to visit the scientific team working there. Their short film, *Cosmic Microwave Background: The New Cosmology,* takes viewers to this forbidding place and shows how scientists are unraveling the story of the universe.

Produced as part of the Rose Center's AstroBulletin program, *Cosmic Microwave Background: The New Cosmology* will be screened at the Museum during regular Museum hours through June 2003 in the Black Hole Theater of the Frederick Phineas & Sandra Priest Rose Center for Earth and Space's Dorothy and Lewis B. Cullman Hall of the Universe. More information about the CMB will be featured on AstroBulletin kiosks in the Cullman Hall of the Universe.

The AstroBulletin employs high-definition video, computer animations, and images from satellites, observatories, NASA, and the Hubble Space Telescope to dramatize cosmic events, explain astronomical concepts, and report recent discoveries in the field of astrophysics. *Cosmic Microwave Background: The New Cosmology* and other elements of the AstroBulletin are made available to museums, science centers, planetariums, and other public spaces nationwide and around the world.

The AstroBulletin is generously supported by Toyota Motor North America, Inc. Significant educational and programming support is provided by the National Aeronautics and Space Administration (NASA).

D. FINNIN/AMNH

AN INTERVIEW
with Ian Tattersall

Co-curator of *The First Europeans: Treasures from the Hills of Atapuerca*

Ian Tattersall is Curator in the Division of Anthropology and author of many books on human evolution including, most recently, The Monkey in the Mirror: Essays on the Science of What Makes Us Human.

Q: What is the significance of this exhibition?

This is the first time outside Spain that this extraordinary material that documents the very earliest attempt by human beings to occupy Europe has been on display.

There are two sites at Atapuerca. One is literally a hole in the ground that's filled with human bones that are thought to be about 400,000 years old. This is the Sima de los Huesos site, or the Pit of the Bones.

There is another site, only half a mile away, called Gran Dolina [where] an enormous sequence of archaeological deposits was exposed. Low down in that sequence were found human bones that are about 800,000 years old, twice as old as the other hominids at the Sima. It's just pure coincidence that these two extraordinary sites are so close to each other.

Q: How does this material fit in with the human fossil record?

We tend to think of human evolution as having been a kind of a single-minded slog from primitiveness to perfection. And it really was not like that at all. It was instead a matter of new species going out into the environment and competing with other life forms, and succeeding or failing and going extinct.

This material that we'll have on display is some of the best evidence that we have for this pattern in human evolution. I think that the earliest material we're going to have on display [from Gran Dolina] was the product of a failed attempt by an early human species to colonize Europe. And the later material is closely related to the Neanderthals who were a species that lost out when *Homo sapiens* finally entered Europe. So here are two separate attempts to be a European, as it were.

Q: You mentioned the Sima de los Huesos, or Pit of the Bones. Why is this site so unusual and intriguing?

Human fossils are not that common and this particular site is the most astonishing concentration of human fossils that has been found anywhere in the world.

Hellish conditions, by the way. Absolutely hellish, horrible, cramped, at the bottom of this shaft in the ground. You have to walk 700 yards into a cave through dark passages in the pitch dark and over a rough floor. And then you have to descend 50 feet vertically down a shaft in the dark 'til you come to a slope that leads down even further into the cavity where these bones collected.

Q: What do these hominids teach us about ourselves or about what it means to be human?

What it mainly teaches us is what a special phenomenon *Homo sapiens* is. There's something qualitatively different about *Homo sapiens* compared to any previous hominid species. I think it's important to understand that we weren't gradually burnished by evolution to do what we do superbly well. We are more like an accidental product that happens to have all these new cognitive capacities and we're still exploring the ways in which they can be used.

Q: You use both the terms "humans" and "hominids." What's the distinction?

There is no universally agreed definition for what "human" means. The word was invented before people knew anything about the apes, let alone before anybody had any concept that we had close extinct relatives. So "human" is a very elusive term. And we do all tend to use it a little loosely—I certainly tend to use it rather loosely. I don't think that it matters, just as long as we realize that what is human is contextual, is something that we sort of intuitively recognize rather than rigorously define. In the strictest sense none of the Atapuerca people were human; but there is something that we can recognize as humanity in all of them.

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THE FIRST EUROPEANS:
Treasures from the Hills of Atapuerca

Through April 13, 2003

The First Europeans will reveal the mysteries of ancient humans in western Europe through exquisitely preserved hominid and animal fossils—some up to one million years old—found in the hills of Atapuerca in the Spanish region of Castilla y León. This remarkable exhibition provides Americans their first-ever glimpse of these "first Europeans," and explores what their existence teaches us about what it means to be human today.

Co-organized by the American Museum of Natural History and Junta de Castilla y León

MUSEUM EVENTS

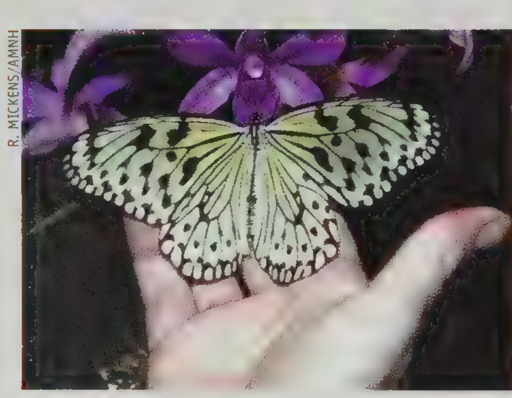
EXHIBITIONS

Einstein
Through August 10, 2003
Gallery 4, fourth floor
This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 26, 2003
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.*


R. MICKENS/AMNH

Remains of a Rainbow: Rare Plants and Animals of Hawaii
Through March 2, 2003
Color and black-and-white photographs of Hawaii's endangered species.

Organized by Umbrage Editions, New York, in association with Environmental Defense.


©2002 NORBERT WU/WWW.NORBERTWU.COM

Under Antarctic Ice
Through March 2, 2003
Spectacular large-format photographs by one of the world's leading underwater photographers, Norbert Wu.

This exhibition is made possible by the generosity of the Arthur Ross Foundation. Developed by Norbert Wu Productions and produced by the Pacific Grove Museum of Natural History.

PERFORMANCES

Einstein and Love
Friday, 2/14, 7:30–9:00 p.m.
Join the "Physics Chanteuse" for a Valentine's Day show that pays tribute to the life and loves of Einstein while exploring physics and more.

Cosmic Cabaret
Sunday, 2/16, 2:00–3:00 p.m.
This vaudeville act for a family audience weaves music and magic with the latest research and theories in physics.

WORKSHOP

Hands-On Einstein
Saturday, 2/8
11:30 a.m.–1:00 p.m. (adults)
2:00–3:30 p.m. (teens, ages 14–17)
Explore the basic physical and mathematical properties of gravity and space-time.

EINSTEIN FOR EVERYONE

The Sun and Its Energy
Saturday, 2/1, or Sunday, 2/23
1:30–3:00 p.m.
Learn about the Sun and how much we depend on it. (Ages 7–9)

An Expedition into Space-Time
Sunday, 2/2, 10:30 a.m.–12:00 noon
Observe a cosmic ray, play with a laser, and learn about black holes. (Ages 7–9)

Adventures in Light!
Sunday, 2/2, or Saturday, 2/22
1:30–3:00 p.m.
You're never too young to start playing with light! (Ages 4–6, each child with one adult)

CHILDREN'S ASTRONOMY PROGRAMS

Journey through the Solar System
Three Wednesdays, 2/5–19
4:15–5:45 p.m. (Ages 10–13)

Space Explorers
Telescope Star Party
Tuesday, 2/11, 4:30–5:45 p.m.
(Ages 12 and up)

A Taste of Things to Come!

To whet your appetite for the exhibition *Chocolate*, opening at the Museum on June 14, the Museum Shop introduces a full selection of Godiva chocolates, just in time for Valentine's Day. Visit the Main Shop and also pick up a copy of the exhibition's delicious companion book, *Chocolate: The Nature of Indulgence.*

GLOBAL WEEKENDS

Black History Month

Movement '63: The Pinnacle of the Civil Rights Struggle in America
Saturday, 2/1–22, 1:00–5:00 p.m.
Films, discussions, and performances of spoken word, poetry, dance, and music honor this explosive period in American history.

HAYDEN PLANETARIUM PROGRAMS

The Train Station at the End of the Universe
Sunday, 2/9, 12:00–3:00 p.m.
Grand Central Terminal, with its breathtaking starry ceiling, will serve as the backdrop for this discussion of selected concepts in astronomy. Wear comfortable walking shoes.

N. TYSON

Grand Central Terminal

Celestial Highlights
Tuesday, 2/25, 6:30–7:30 p.m.
This monthly tour of the heavens offers a view of the constantly changing night sky.

Courses

Using a Telescope
Four Mondays, 2/3–3/3, 6:30–8:30 p.m.
This course covers the basic functioning of telescopes as well as locating celestial objects and using charts and other aids for observation.

The Science of the Rose Center
Five Tuesdays, 2/4–3/4, 6:30–8:30 p.m.
Join five of the scientists who developed the Rose Center's content on an in-depth exploration of the planets, stars, galaxies, and the universe.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford. Every half hour Sunday–Thursday and Saturday, 10:30 a.m.–4:30 p.m.; Friday, 10:30 a.m.–7:30 p.m.

NASA

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

LARGE-FORMAT FILMS

In the Samuel J. and Ethel LeFrak IMAX® Theater

Pulse: a STOMP Odyssey
Take a rhythmic voyage of discovery around the world of percussion.

Kilimanjaro: To the Roof of Africa
Follow a team of hikers up Africa's highest mountain.

INFORMATION

Call 212-769-5100, or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

AMNH eNotes delivers the latest information on Museum programs and events to you via email. Visit www.amnh.org to sign up today!

Now *Starry Nights: Fridays under the Sphere* comes right into your home in a live broadcast by **WBGO, Jazz 88.3 FM.**

Tune in **Friday, February 7, at 5:30 p.m.** for the best in world-class jazz, live from the Rose Center for Earth and Space.

Media Sponsorship for Starry Nights *is provided by CenterCare Health Plan.*

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- Discounts in the Museum Shop, restaurants, and on tickets to programs
- Free subscription to *Natural History* magazine and to *Rotunda*, our newsletter
- Invitations to Members-only special events, parties, and exhibition previews

For further information about all levels of Membership or to enroll, call the Membership Office at (212) 769-5606 or visit www.amnh.org.

Homing Instinct

By Jeff Fair

By the time I hired on to survey the common loon population of northern New Hampshire, back in 1978, bald eagles were long gone as a nesting species. Shot as predators, trapped for the taxidermy trade, left homeless as, one by one, their ancient nesting trees were sawed out from under them, and then poisoned inadvertently to the brink of extermination by insecticide, our national symbol had little reason to stick around. The last pair of bald eagles in New Hampshire had nested near the top of a huge old white pine tree near the western shore of Lake Umbagog. They laid their final clutch of eggs in 1949, then disappeared.

Years passed. Sometime in the late 1960s that last eagle nest, long-empty and derelict, tumbled out of its tree and crashed to the ground.

More years passed. Occasionally an eagle appeared near Lake Umbagog. Observations became more frequent. By 1981 I was spotting bald eagles during many of my surveys around the lakeshore, their white heads and tails glowing like spotlights against the dark alder and fir. Sometimes one would perch in the old "eagle tree."

In 1987 a raptor biologist working on Lake Umbagog observed a bald eagle with a yellow tag in its wing. The tag identified the bird as a male abducted in 1984 from a nest in Alaska and released in New York State as part of the eastern recovery effort. He seemed quite willing to resettle here: by 1988 he was seen regularly in the company of an adult female. That was the summer I heard voices from a tree.

I was in my canoe near the shoreline of a quiet backwater, more than a mile from the lake and the eagle tree, searching for the nest of a pair of loons I had been tracking all summer. Suddenly I heard the English language issuing forth from the top of a tall pine nearby. I paddled over to investigate. The tree became very quiet. After a few minutes, a human form descended the tree trunk. I observed that she was none too happy at being discovered.

Somewhat reluctantly she explained that a small team from the Audubon Society was constructing a nest replica to entice the new eagle pair. The tree seemed a safer site for a new eagle nest than the exposed top of a tree on the lakeside, where the team feared duck hunters might shoot the eagles, or (far more likely, I thought) bird-watchers might love them to distraction. Regardless, the initiative under way above us was an act of wildlife management, highly classified, and I was sworn to secrecy.

I never did find the loon nest, but late that summer we saw the eagles carrying sticks, and we knew something was happening. By the following spring they had finished installing a huge and ungainly pile of branches near the top of a tall white pine—not the tree that had been chosen for them, but the very same tree where the last active eagle nesters had made their home in 1949.

Three-week-old eagle chicks in the "eagle tree" nest on Lake Umbagog

How did a young eagle, hatched a continent away and belonging to a species that had not nested in these parts in four decades, come to choose the eagle tree? We may never know the answer. It is enough for now to observe, in a time of population modeling and species management, that these patterns of resilience, of hope itself, are carried within the individual: a young eagle, an ancient pine, perhaps even a dutiful field biologist, kneeling in his canoe.

Jeff Fair has visited New Hampshire's Lake Umbagog every year since 1978 to count loons and listen for voices in the trees.

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NATURAL HISTORY

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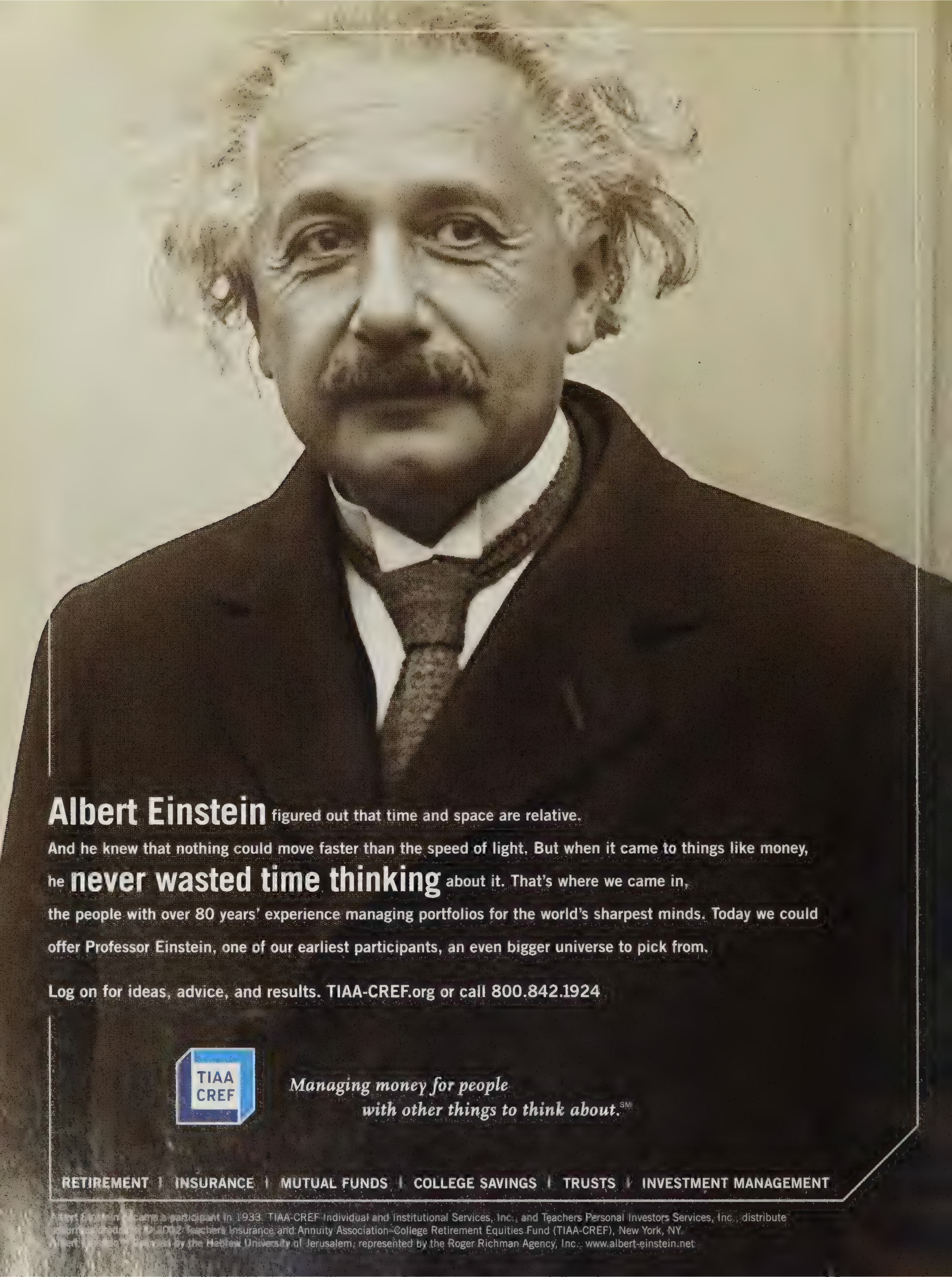
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NATURAL HISTORY

MARCH 2003 VOLUME 112 NUMBER 2

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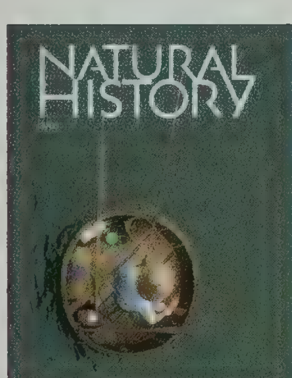

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Vietnamese fishing raft

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PHOTOGRAPH BY ROBERT VAN DER HILST

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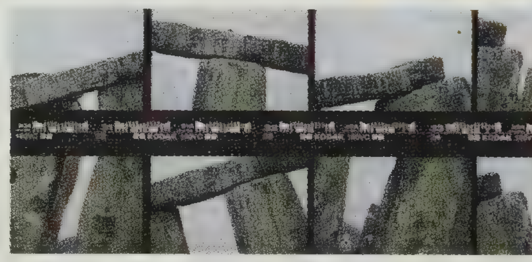

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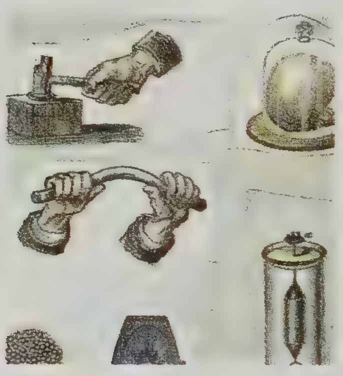

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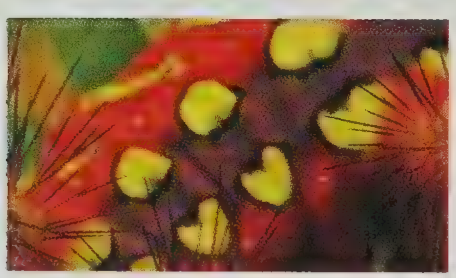

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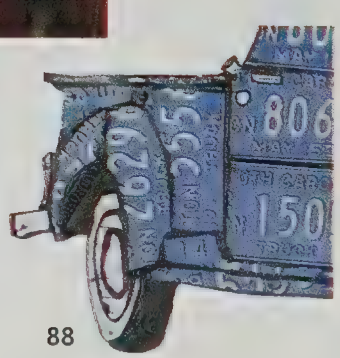

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UP FRONT

This Stop Is Vietnam

Isn't it odd, really, that so much of what we outsiders know about Vietnam is colored by the memory of the war? As someone who came of age in the late 1960s, I still find it hard to put aside the terrible associations some of the names conjure: Mekong River, Gulf of Tonkin, Ho Chi Minh trail (soon to be a major superhighway), even the description "mountains and jungles of Vietnam." Yet behind those names from ten thousand wartime dispatches is a land that is home to an incredible diversity of life-forms, including literally hundreds of species new to science that were hidden by decades of conflict.

Vietnam lies at the center of a tectonic traffic jam. Mountains and rivers arose from collisions of three tectonic plates, creating an immense variety of ecosystems in the country as well as some formidable barriers to species migration. Swings of climate—hot and cold, wet and dry—buffeted the landscape. During ice ages long ago, sea levels plunged and the continental shelf off the shores of Vietnam turned into dry land. Some species roamed across the newly exposed land. Then, when the climate warmed and sea levels rose again, populations became trapped and isolated on newly created islands. Other species, which once ranged freely across cool valleys, were chased up to cooler mountains as the lowland climate began to warm; eventually they became isolated by altitude instead of by seawater. With time, the isolated populations evolved and diverged, then remixed when the barriers to their spread eventually receded once more.

With this issue the editors of *Natural History* invite you back to Vietnam, a country that has become both a hot tourist destination and an ecologist's dream. Join Nguyen Thi Dao as she recalls running as a child through the forests of Cuc Phuong National Park, Vietnam's oldest national park (see "My Life as a Forest Creature," page 70). Marvel at photographer Mark Moffett's glorious image of a caterpillar native to the rainforests of Vietnam (see "Pretty Poison," page 10). Enjoy the reminiscences of Le Anh Tu Packard, as she recalls the aromatic dishes her grandmother flavored with the sublime extract of the *ca cuong,* the water bug that for the Vietnamese is practically a symbol of the highest culinary art (see "Bug Juice," page 63). Finally, take a field trip with Eleanor J. Sterling, Martha M. Hurley, and Raoul H. Bain (see "Vietnam's Secret Life," page 50) to discover how the nation's rich biodiversity, coupled with the crazy-quilt complexity of its ecosystems, arose directly from the pushes and pulls of its turbulent climatic and geologic history.

Thus informed, you won't want to miss the new exhibit at New York City's American Museum of Natural History, "Vietnam: Journeys of Body, Mind, and Spirit," opening March 15.

• • •

As this issue of *Natural History* goes to press, we have just begun to mourn the loss of the seven astronauts who perished in the breakup of the space shuttle *Columbia*. Our hearts go out to their families, to their extended family at NASA, and to all our readers who share in the sadness of this tragedy.

—PETER BROWN

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Pretty Poison

Photograph by **Mark Moffett**

THE NATURAL MOMENT

◄ *See preceding pages*

To be seen or not to be seen? Most slug caterpillars survive their vulnerable youth by making a visual statement. Orange-tinted skin, black body rings, and piercing yellow eyespots mark the Vietnamese larva of *Setora fletcheri* pictured here. But this brazen display fades away with adolescence. First the flashy spikes collapse. Then a spherical cocoon is spun. The brown, mature moth finally emerges with a more conservative strategy: to blend in.

Not all of the slug caterpillar's decoration is just for show. At any sign of danger, each cluster of spines blooms into a bristly sphere. Glands at the base of the spines produce venom rich in histamines—liquid peril for any would-be attacker.

Photographer Mark Moffett stealthily approached this *S. fletcheri* in Tam Dao National Park, north of Hanoi, where the mountains rise from the fertile Red River Delta as "islands in a sea of clouds." The description well suits the numerous and distinct niches that isolate the residents of Tam Dao, making it a kind of untapped, continental Galápagos, teeming with exotic organisms. Trekking at twilight in the park, Moffett spotted this larva shining on the path. Even in the dark, he notes, it glowed "like a marine creature"—much too extravagant to resist.

—*Erin Espelie*

LETTERS

All in the Family?

In his search for differences between Neanderthals and modern humans, Juan Luis Arsuaga ["Requiem for a Heavyweight," 12/02–1/03] may have missed the importance of similarities. He thinks no Neanderthal genes have reached us, but why should we even assume genes specific to Neanderthals existed? Even though today we can readily distinguish, say, Europeans from Aboriginal Australians, their distinctive characteristics do not reflect unique genes. Different human groups simply have different proportions of certain genetic variations (such as blood types A, B, AB, or O). So some other kind of evidence of Neanderthal ancestry is needed.

Studying Pleistocene Europeans, my colleagues and I found a long history of gene flow between various populations, including Neanderthals. And in a study of anatomical similarities, we could not dismiss the possibility that half the ancestors of early modern Europeans were Neanderthals. Of course, evolution has continued to modify genes and anatomy, and there are no Neanderthals left. But Mr. Arsuaga might indeed be carrying that drop of Neanderthal blood.

Would a Neanderthal pass unrecognized on a New York subway? Probably. The artist Karen Harvey built up muscle and flesh around a cast of the skull of the 70,000-year-old La Ferrassie Neanderthal [*see illustration below*]. I wonder how many men as good looking as this fellow were

straphanging this morning on the A train.

Milford H. Wolpoff
University of Michigan
Ann Arbor, Michigan

In my view, modern humans evolved in situ from Neanderthals in Europe, as they did from robust forms elsewhere. Furthermore, the two manifestations of human form could never have encountered each other, because only one existed at any given time.

Abundant archaeological research has shown that the in-situ refinement of late Mousterian tools gave rise to the toolmaking traditions of the subsequent Upper Paleolithic. The late so-called Neanderthals who made those tools were almost indistinguishable from the early "moderns"—the Cro-Magnons—who succeeded them. Moreover, Cro-Magnon teeth and degrees of robustness are exact equivalents of late Neanderthal teeth and degrees of robustness.

C. Loring Brace
Museum of Anthropology
University of Michigan
Ann Arbor, Michigan

JUAN LUIS ARSUAGA REPLIES: Neanderthals and modern humans were two morphologically different types. Their skeletal differentiation was substantially greater than that of closely related present-day species such as lions and tigers, which can interbreed in captivity but don't usually mix in nature. But even substantial morphological differences between two populations do not necessarily imply the populations are genetically isolated (unable to interbreed).

Neanderthals evolved in Europe from their Middle Pleistocene ancestors. Modern humans appear later in the European fossil record; either they evolved locally from the Neanderthals (as Mr. Brace states), or they came from elsewhere and replaced the Neanderthal "aborigines." I think the second scenario is the more likely. Nevertheless, Neanderthals and modern humans could have interbred locally on a small scale, and Neanderthals could thereby have contributed to the gene pool of the earliest modern human population in Europe. If the gene contribution was small, though, those rare Neanderthal genes would probably have disappeared in a few millennia, long before the present—unless the Neanderthal genes gave their bearers greater fitness. If the morphological differences between Neanderthals and contemporary humans resulted from different frequencies of the same genes, as Mr. Wolpoff

states, those unique Neanderthal gene combinations have been lost.

But my two colleagues and I agree on something quite important: Neanderthals had a human mind. They had self-consciousness and language, engaged in rituals, made long-term plans. Some investigators divide all past and present beings into just two categories: they (creatures without a mind) and we (the present-day human species). I say Neanderthals were on our side of the line.

Central Questions

Neil deGrasse Tyson's "Delusions of Centrality" [12/02–1/03] comes close to saying what I would put this way: Because everything in the observable universe began expanding from the same point, wherever one happens to be is, for all practical purposes, the center of everything. What to us appears to be a faint proto-galaxy near the edge of the universe is, to its inhabitants, the center of their own expanding and uniformly distributed universe. It is as correct for each of us to say "I am at the center of everything" as it is to say there is no center. One is entitled to feel as important or as humbled as one's temperament dictates.

Robin C. Chapman
Virginia Beach, Virginia

I take exception to Neil Tyson's version of the history of science. He accepts the pandemic presumption that Earth's centrality in the Ptolemaic system implied our specialness. On the contrary, for medieval writers "central" implied "low," and the very center was the very lowest. That's why Dante placed Hell dead center in his universe. That's why Pico said we Earth-dwellers inhabit "the excrementary and filthy parts of the lower world."

Copernicus's removal of the Earth from that cosmic pit was not a demotion but a *pro*motion. Galileo thus exulted that, in the new cosmology, Earth was no longer "the sump where the universe's filth and ephemera collect" but was now free to join "the dance of the stars."

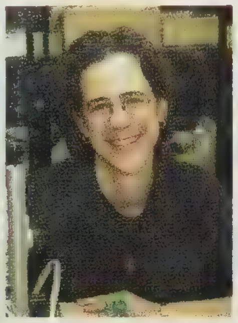
Dennis Danielson
University of British Columbia
Vancouver, Canada

NEIL DEGRASSE TYSON REPLIES: Mr. Danielson implies that I and my 6,000 astrophysicist colleagues around the world are all deluded. Perhaps so. But not without good cause. If the center of the universe were indeed a cosmic slag heap and not a special place, why did everybody get so upset when they learned it might not be occupied by Earth? Why was Copernicus afraid to publish his heliocentric system? Why was Galileo subjected to the Holy Inquisition? The psychology of human behavior argues differently from the phantasmagoria of Dante and Pico.

Natural History*'s e-mail address is nhmag@amnh.org.*

CONTRIBUTORS

Mark Moffett ("The Natural Moment," page 10) made his first foray into tropical rainforest research at the age of seventeen, catching snakes for a Costa Rican expedition led by naturalist Max Nickerson. Moffett continued to explore rainforest habitats as a graduate student at Harvard, where he studied under the evolutionary biologist E.O. Wilson. While doing his dissertation in biology, Moffett traveled for more than two years in Asia, teaching himself photography in his spare time. He has won international awards for his pictures, some of which were exhibited in twenty-five countries as part of the 1992 World Press Photo exhibition. He photographed the brilliantly colored slug caterpillar in northern Vietnam.



Conservation biologist **Eleanor J. Sterling** *(far left)* ("Vietnam's Secret Life," page 50) is the director of the Center for Biodiversity and Conservation (CBC) at the American Museum of Natural History in New York City. She has spent the past fifteen years engaged in field research, studying threats to biodiversity. Coauthor **Martha M. Hurley** *(center left)* is a postdoctoral research fellow at CBC. She is part of the team analyzing data from the CBC's biotic survey in Vietnam, under way since the late 1990s. Together with Sterling and their colleague Minh Duc Le, Hurley is also coauthor of a forthcoming book that will highlight Vietnam's remarkable biodiversity. Coauthor **Raoul H. Bain** is a herpetologist who earned an M.Sc. in zoology from the University of Toronto, with a focus on the diversity of Southeast Asian amphibians. He began doing scientific fieldwork in British Columbia as a technician in paleontology and has since worked in Alberta, Tennessee, and the Bolivian Andes. Bain has made four field trips to Vietnam since 1995. The publication of Sterling, Hurley, and Bain's article coincides with the exhibition "Vietnam: Journeys of Body, Mind, and Spirit," which will open at the American Museum of Natural History on March 15.

Robert L. Smith ("On the Scent," page 60) has been sorting out the paternal behavior of water bugs for more than two decades. When he read **Le Anh Tu Packard**'s reminiscences of the aromatic condiment derived from one water bug species, *Lethocerus indicus* ("Bug Juice," page 63), he was charmed and also eager to supply the scientific side of the story. Smith is an associate professor of entomology at the University of Arizona in Tucson. He recently collaborated with the zoologist Arja Kaitala to tell *Natural History* readers about another critter, "The Bug That Lays the Golden Eggs" (March 2002). Packard was born in Thailand of ethnic Vietnamese parents, and raised mainly in Bangkok, Yangon (Rangoon), and New York City, but as a child she also lived for more than half a year in Vietnam. She now appreciates many cuisines, but the flavors she grew up with still call to her. An economist based in Pennsylvania, Packard often returns to Vietnam on missions for the United Nations and the World Bank. She is a technical advisor to Vietnam's finance ministry and an academic advisor to a nonprofit Vietnamese research organization.

An art enthusiast as well as an astrophysicist—and thus well versed in mathematics—**Mario Livio** ("The Golden Number," page 64) recently combined his passions to delve into the mysteries of a number that pops up repeatedly in both nature and human creativity. The result was his recent book, *The Golden Ratio: The Story of Phi, the World's Most Astonishing Number* (Broadway Books, 2002). Born in Romania, Livio holds a doctorate in theoretical astrophysics from Tel Aviv University and is now head of the science division at the Space Telescope Science Institute in Baltimore, Maryland—the organization responsible for the scientific program of the Hubble Space Telescope. Livio is also the author of *The Accelerating Universe: Infinite Expansion, the Cosmological Constant, and the Beauty of the Cosmos* (John Wiley & Sons, 2000).

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By Stéphan Reebs

DRINKING IN THE DARK Far from city lights, with only the Moon and stars to guide them, people see in shades of gray. That's because our eyes have just two kinds of photoreceptors—rods and cones—and the rods, the only receptors that work well in dim light, do not detect color. Until recently, biologists had assumed that all animals shared the same visual limitation. But the animal world has a knack for coming up with species whose sensory powers surpass our own. This time, a humble nocturnal moth is our superior.

The elephant hawkmoth *(Deilephila elpenor)* locates flowers in the dark of night and feeds on their nectar. When the moth's cousins, the butterflies, seek nectar in the daytime, they rely on color to distinguish and remember flowers particularly rich in nectar. Almut Kelber, Anna Balkenius, and Eric J. Warrant, all biologists at Lund University in Sweden, thought that having color vision would be just as useful for the nocturnal hawkmoth. So they set out to prove for the first time ever that at least one animal can perceive color at night.

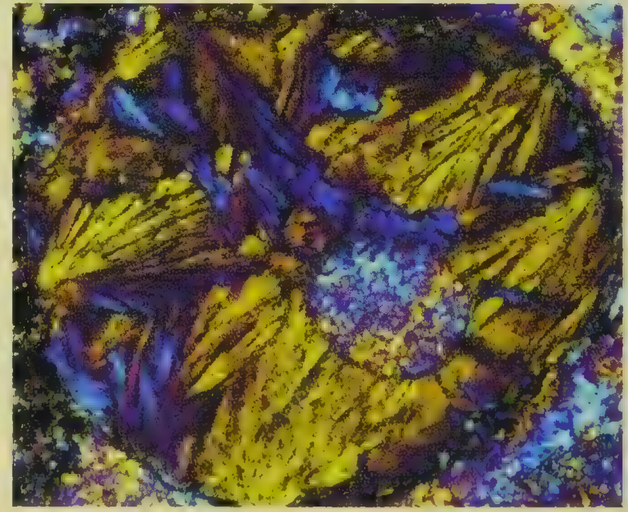
Elephant hawkmoth (actual size), foraging by color

Under limited light, similar to that of late dusk, Kelber and her colleagues trained sixteen hawkmoths to find the sugar solution placed in the centers of artificial flowers. Some hawkmoths were trained to seek the blue flowers, others the yellow ones. Then the biologists dimmed the room to the level of starlight and presented the moths with a display of variously colored circles (minus the sugar solution). One circle was the animal's training hue (blue or yellow); the rest were various shades of gray. Almost unfailingly the moths chose—that is, touched first—the color to which they had been trained. By contrast, six people asked to discriminate among the disks under the same low light failed miserably. Once again, it seems, we are bested—though we do have the brains to prove this fact to ourselves. ("Scotopic colour vision in nocturnal hawkmoths," *Nature* **419:**922–25, October 31, 2002)

AFTERMATH OF A CATACLYSM Most scientists agree that about 65 million years ago a catastrophic meteor impact wiped out the dinosaurs. That collision, however, is dwarfed by events that took place billions of years earlier, when the Earth was only a billion years old.

According to Gary R. Byerly, a geologist at Louisiana State University in Baton Rouge, and his colleagues, during the Earth's early history four meteors slammed into the planet with such force that they vaporized rocks for hundreds of miles around. The clouds of rock vapor quickly condensed and fell back to Earth as a rain of small rounded particles called spherules.

Spherules occur in what are now South Africa and western Australia, embedded in layers of sedimentary rock that contain unusually abundant, and thus demonstrably extraterrestrial, chromium isotopes and iridium. The spherules are mixed up with inorganic detritus, perhaps because of a tsunami—also generated by the collision—that sloshed back and forth across the Earth. Some of the spherule beds are as much as a foot thick, so the impacts that created them must have been enormous. By comparison, the impact layer left by the meteor that did in the dinos is less than an inch thick.



Spherule—a raindrop made of rock

Byerly and his coworkers have analyzed the lead isotopes in small zircons extracted from the lowest (hence the oldest) spherule-studded layer. The relative abundance of those isotopes, which reflect the slow decay of uranium over the millions of millennia since the spherules were formed, has enabled the geologists to calculate the age of the layer: nearly 3.5 billion years. That makes it the earliest evidence discovered so far of an asteroid impact. In those days, bacteria were the Earth's principal life-forms, and they've turned out to be a lot tougher than the dinosaurs. After all, they're still with us. ("An archean impact layer from the Pilbara and Kaapvaal cratons," *Science* **297:** 1325–27, August 23, 2002)

FROZEN DINNERS One September afternoon a dozen years ago, two hikers came across a mummified man at the edge of an alpine glacier in northern Italy. Now known as the Tyrolean Iceman, or Ötzi (after the Ötzal Alps, where he was discovered), the 5,200-year-old corpse has been the subject of much analysis and discussion, including conflicting assertions about his diet.

Now, adding to earlier investigations into Ötzi's diet, the molecular anthropologist Franco Rollo and his colleagues, all of the University of Camerino in Italy, have extracted intact DNA fragments from the mummy's intestinal contents and compared the DNA with known sequences from modern plants and animals. Their analysis shows that Ötzi's second-to-last meal (the remains lower down in the intestinal tract) included the meat of an ibex (a wild goat), cereals (grains of the grass family, possibly cultivated), and various other plants. His last meal was red deer meat.

Today the red deer *(Cervus elaphus)* is at the periphery of human affairs. Five thousand years ago, however, Europeans relied heavily on the animal. Carvings depicting red deer occur prominently at Neolithic alpine archaeological sites. Some of the equipment Ötzi carried (a curved spike, an

Ötzi the Iceman

edge sharpener for stone tools, a quiver) was made from the red deer's skin or antlers. And some historians maintain that people deforested Europe during the Mesolithic period to favor the growth of red deer herds. The creature is thus thought to have been on early continental menus—an inference that Rollo and his colleagues have now directly confirmed. ("Ötzi's last meals: DNA analysis of the intestinal content of the Neolithic glacier mummy from the Alps," *Proceedings of the National Academy of Sciences* **99:**12594–99, October 1, 2002)

EXPERIMENT OF THE MONTH Any runner knows that if you want to cover a long distance, you shouldn't start too fast. And that may be a sound rule of thumb for a runner's entire lifetime. Experiments with people as well as with laboratory animals continually demonstrate that rapid growth leads to early death. Now it appears that the same trend holds for some wild animals, too.

Mats Olsson, now at Göteborg University in Sweden, and Richard Shine of the University of Sydney in Australia captured pregnant southern snow skinks *(Niveoscincus microlepidotus)* at the summit of Mount Wellington on Tasmania and then placed their newborns in pens on the same mountain. The pens encompassed the skinks' natural habitat, and the baby animals were individually marked and given plenty of extra worms to eat. Four times during the first three months of their lives, the little reptiles were caught and weighed to establish their growth rate. Then they were released into the wilderness at the mountain's summit.

Southern snow skink (adult version)

Twice in the next four years the investigators recaptured the skinks across an area that far exceeded the animals' capacity for travel. Individuals that weren't recaptured were thus presumed to have perished. As the biologists expected, skinks that had grown fast as youngsters—raised, one might say, with a silver spoon—figured prominently in the group of missing individuals. That silver spoon, say the authors, "may sometimes be tarnished."

The physiological reason for the link between fast growth and lower life expectancy is still unclear, but the implication for evolutionary studies is important. Although fast growers generally outcompete their rivals during any given reproductive season, in the course of a lifetime they may not leave more offspring in the next generation, contrary to what has commonly been assumed. Olsson and Shine say the slow starters may compensate for their languid pace by living longer and getting more chances to breed. ("Growth to death in lizards," *Evolution* **56:**1867–70, September 2002)

CORE VALUES Besides preserving the occasional frozen mummy, glaciers and ice fields contain evidence of the climates of long ago. As ice is consolidated from the annual snowfall, the quantities and composition of dust and atmospheric gases trapped in the ice signal spells of wet and dry, hot and cold. For glaciologists, examining an ice core extracted from the depths of a glacier is like reading the table of contents of a history book.

Ice cores recently extracted from the top of Mount Kilimanjaro, the highest peak in Africa, have now yielded a picture of tropical climate change for the past 12,000 years. Glaciologist Lonnie G. Thompson of Ohio State University in Columbus and an international team of geoscientists drilled down to the bedrock to extract cores as long as 167 feet. Analysis has shown that major droughts took place about 8,300, 5,200, and 4,000 years ago; the latter two dates coincide with known societal upheavals in Africa and the Middle East. Overall, however, Africa's climate was relatively warm and wet from about 11,000 to 4,000 years ago, becoming drier and cooler thereafter.

But the cool phase is over. In the past 100 years, Kilimanjaro's ice fields have shrunk 80 percent. At current warming rates the frozen fields, which have survived for aeons just south of the equator, are expected to vanish by the year 2020. ("Kilimanjaro ice core records: evidence of Holocene climate change in tropical Africa," *Science* **298:**589–93, October 18, 2002)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

SPRING BREAKS

Get away from it all
on an exciting birding adventure

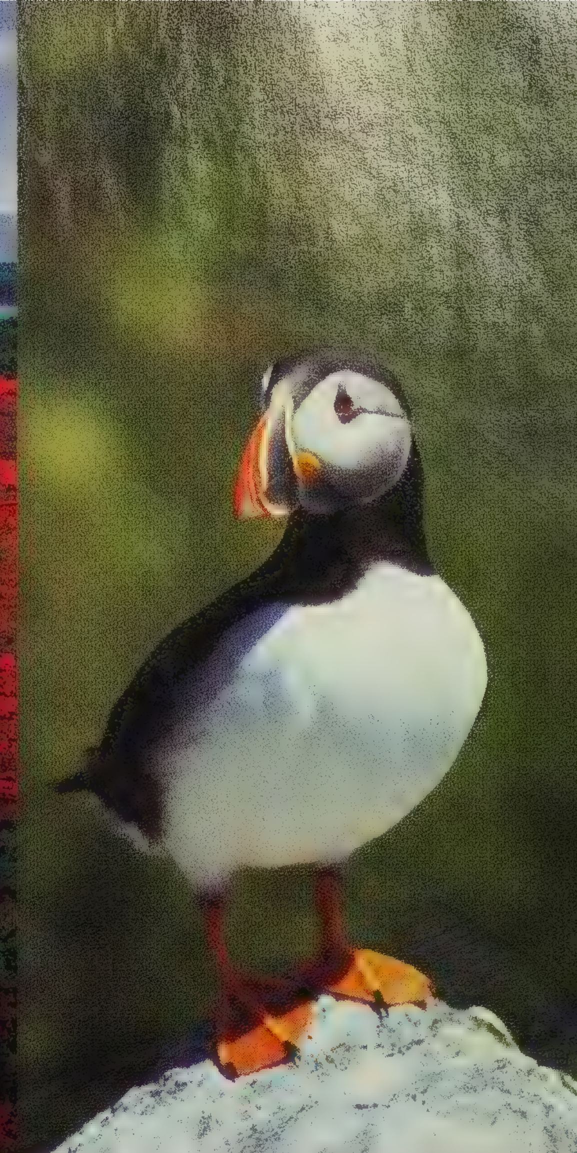
NEW BRUNSWICK

Welcome to New Brunswick, Canada...where bird-watchers answer the call of Sandpipers, Plovers, Bald Eagles, Puffins and rare waterfowl! From island retreats to protected marshes and preserved habitats, this is an ecological haven for millions of winged creatures.

NEW BRUNSWICK'S BAY of Fundy, **One of the Marine Wonders of the World**, is a prime feeding ground for migrating birds. **Campobello Island** and **Grand Manan Archipelago** (one of Thayer's Top 100 Birding Hot Spots) are located at the mouth of the bay and are home to more than 390 species of birds. John James Audubon, author of *Birds of America*, discovered and sketched some entirely new bird species here. Nearby **Machias Seal Island** is one of the few Puffin colonies in the world where visitors can go ashore and view them in their natural habitat.

Farther along the Fundy Coast, make sure you stop and tour the gleaming mud flats of the **Irving Nature Park** in Saint John, a 600-acre estuary acclaimed for its amazing bird staging area. And visit the interpretative centre of nearby **Fundy National Park** to discover why Fundy's ecosystem is so important to many of North America's rare birds. The park is also home to a network of coastal trails where you can catch sight of shorebirds reeling in the tidal wake.

Over on the Acadian Coast, you'd better bring your binoculars to the wildlife reserve at **Cape Jourimain Nature Centre**...over 170 different species of birds are protected here by the Canadian Wildlife Service! In Sackville, visit the **Tantramar Marshes**. Situated on one of North America's major migratory bird routes, they offer prime nesting and feeding grounds for Marsh Hawks and countless waterfowl. Constructed over 200 years ago, the marshes are the largest man-made



agricultural land mass in Canada and home to the **Sackville Waterfowl Park**. This 55-acre park has a network of boardwalks and walkways which allows species such as the Common Snipe and the Tree Swallow to be observed without harming the lush grasses and wetlands in which they thrive.

Continuing up the coast you'll discover a provincial eco-treasure…the **Irving Eco-Centre, La Dune de Bouctouche**. "The Dunes," as they are known locally, also offer an extensive boardwalk system along one of the last remaining white sand dunes on the northeastern coast of the continent. Here you will see rare plants as well as spot the Tern and endangered Piping Plovers as they nest in the fragile marshes.

Head up to the northeastern tip of the province to the serene **Miscou Island**, the site of the Oldest Lighthouse in Eastern Canada and home to a burgeoning bird sanctuary. You'll find Yellowlegs, Sandpipers, Northern Gannets and many more on Miscou's spectacular coast. You should see the island in the fall…the thick brush that covers the bogs for miles on up to the lighthouse turns an amazing fire red. It makes for an incredible birding backdrop!

It's all part of the wonder of bird-watching…and it's waiting for you next door in New Brunswick, Canada!

Above left: One of many exquisite, pristine waterfalls at Fundy National Park; above center: Autumn Ablaze - the spectacular red peat bogs of Miscou Island; top right: the colorful Atlantic Puffin; bottom right: A bird-watcher's paradise, Cape Jourimain Nature Centre.


Walk on the
Ocean Floor...
In New Brunswick, Canada's Bay of Fundy
Just the Beginning of the Wonder Next Door!
Uncover the Eco-Treasures of
Our Discovery Beaches
and Some of the Continent's
Most Distinctive Dunes!
Visit the Irving Eco-Centre, La Dune de Bouctouche, and tour the botany and biology of one of the last sand dunes on the northeastern coast of the continent. Search for fossils and seash on our Discovery Beaches... the undiscovered treasures of New Brunswick's over 2,065 kilometres (1,200 miles) of coastlin
Irving Eco-Centre, La Dune de Bouctouche
Experience the
Bay of Fundy...
One of the Marine
Wonders of the World!
The world's highest tides... they happen here twice every day! See so many different species of whales! Walk on the ocean floor and only hours later, kayak above the same spot! It's our Bay of Fundy... an incredible natural phenomena... It's just the beginning of the wonder in New Brunswick, Canada!
Grand Manan Island
Grand Falls Gorge
Tour Miles of the Maritimes'
Most Spectacular Rivers.
The St. John River reaches from the Bay of Fundy up beyond the breathtaking Grand Falls Gorge! The legendary Miramichi calls fly fishers from around the world to challenge miles of salmon fishing paradise. On the Restigouche, you can canoe through the unspoiled wilderness for days on end.
Find New Inspiration Touring Some of
Earth's Oldest Mountains!
The Appalachians are a mantle of wondrous natural beauty and you'll be awed by their untouched vastness. Canoe the lakes and rivers that the mountains frame. Hike endless trails to lookouts that are not only breathtaking... they are inspiring.
Appalachian Range

Millions of Visitors Fly In...
Visit the Bay of Fundy's Grand Manan Archipelago (one of Traveler's Top 100 Birding Hot Spots) as well as Campobello Island! These rich ecosystems attract Atlantic Puffins, Crossbills, Northern Waterthrush, Boreal Chickadees, and Black-Legged Kittiwakes - just to name a few!
Lamèque Island
Atlantic Puffin
Over 300 Bird Species Cross New Brunswick's Skies.
Discover the bird sanctuary in Lamèque as well as Miscou Island's spectacular coast where Yellowlegs, Sandpipers, Northern Gannets, and others come to spread their wings. Experience the spectacular view at Cape Jourimain Nature Centre and spot a Bald Eagle's nest. At the Irving Eco-Centre, La Dune de Bouctouche, see where Great Blue Herons and the endangered Piping Plovers thrive.
Cape Jourimain Nature Centre
The Hopewell Rocks at low tide. 6:25 AM
9:30 AM
1:00 PM
Tide times vary daily.
Succulent Seafood, World-class Cities & Wonderful Seaside Inns!
There's so much seafood... from freshly caught lobster to king-size Atlantic salmon... all cooked in unique local recipes or just the way you like it! When the day is through, spend a night tucked away in a cosy seaside inn, a downtown hotel or a luxurious B&B! Where else could you find world-class cities with so much to offer, so close to incredible natural wonders!
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Canada
Discover our true nature

The Cayman Islands are known for their pristine beaches, but they are also home to over 220 bird species such as the brown booby (below).

CAYMAN ISLANDS

Nestled in the calm, turquoise waters of the western Caribbean is the peaceful British Crown colony known as the Cayman Islands.

SOUTH OF CUBA—AND JUST 480 miles south of Miami—the Caymans consist of a trio of islands: Grand Cayman, Cayman Brac, and Little Cayman. All are blessed with sun-kissed beaches, waters teeming with fish flecked with gold, and a grand 500 years of culture, history, and beauty. But the Caymans are also home to over 220 bird species, including the Cayman parrot, *Amazona leucocephala caymanensis*, one of two subspecies found only in the Caymans (the other subspecies are in Cuba and the Bahamas).

Patricia Bradley

You can spot this native bird along the National Trust's Mastic Trail, a restored 200- year-old footpath through a 2-million-year-old woodland area located in the dense interior of Grand Cayman Island. The picturesque trail winds from swamplands tangled with black mangroves to forests; past mango, tamarind, and calabash trees and delicate wild banana orchids to grassy glades dotted with palm trees. The best time to see the Cayman parrot is February through May; you'll often find it nesting in the hollow tops of dead royal palms during March and April. Be on the lookout for Caribbean dove, West Indian woodpecker, Cuban bullfinch, and smooth-billed ani. Book a guided tour at (809) 949-1996.

Established in 1990, the 180-acre National Trust Brac Parrot Reserve protects the nesting area of the endemic, endangered Cayman Brac parrot *Amazona leucocephala hesterna*. The latest census estimates about 400 of these lovely, iridescent emerald green parrots on the Brac. This endangered subspecies of the Cuban Amazon parrot can be seen in this unspoiled tropical woodland from February through May. The noisy parrots nest during March and April, loudly announcing the beginning of spring. Book guided tours at 345-948-2222.

Booby Pond Nature Reserve on Little Cayman, a 204-acre site comprising a saltwater pond and surrounding mangrove habitat, is a natural rookery, home to an estimated 5,000 nesting pairs of red-footed boobies (one of the largest breeding colonies in the Western Hemisphere). Boobies mate for life and nest from February through July in the mangrove trees within the sanctuary. You'll also find 200 pairs of magnificent frigate birds. While on Little Cayman, keep an eye out for migratory shorebirds, which are seen frequently here. You're likely to see waders as well as a variety of herons, stilts, and even the endangered West Indian whistling duck. You may also see the whistler in the North Side district of Grand Cayman at the Willie Ebanks Farm (located at the end of Hutland Road). The farm is also home to blue-winged teals, coots, grebes, and an occasional osprey or peregrine falcon.


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The Cayman Brac Family Vacation.
Looking for a special getaway that offers more for your family than aquariums and roller coasters? How about looking at the island of Cayman Brac in the Cayman Islands? During our exclusive family escape week from July 13-20th,
your family can explore island caves on a guided spelunking adventure. Take diving certification classes. Go on bird sightings with an expert guide and see birds found nowhere else. Discover Cayman Brac. And discover something special – your family.
Space for the Cayman Brac Family Escape— July 13th-20th, 2003— is limited, so reserve your family's vacation escape now!
Cayman Airways
CAYMAN ISLANDS
Go to NatureCayman.com for information and reservations, or call 1-866-THE-BRAC.

Then loosen up at the corner pub.

Scotland's fascinating heritage and engaging traditions are the stuff of poetry and legend. Marching bands and the haunting tones of bagpipes have stirred emotions through the ages and around the world. But there's so much more to love about Scotland ... enchanting European cities bursting with life and teeming with culture; the wild loveliness of our countryside; ancient, mysterious castles that echo Scotland's romantic past; and the exuberance and friendliness of our people - perhaps nowhere more so than in the warmth of a local pub. Come to Scotland. Come for the love of it!

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VisitScotland

Scotland

Savor the past. Seize the moment.


Shorebirds are a common sight along the northern Scottish coastline

Scottish Viewpoint

SCOTLAND

A land of mountains and moors, deep clear lochs and glens, Scotland attracts birds and birdwatchers with its natural splendor.

BRING YOUR BINOCULARS when you hike across its hills and moors strewn with heather or visit its myriad islands bathed in northern light, for you will find a plethora of birds in Scotland.

You'll find eagles on the beautiful Isle of Skye and ospreys at Loch Garten, nesting red-throated divers in Islay, and corncrakes in Lewis. Visit the famous Scottish Highlands during springtime and you may spot the capercaillie, Scottish crossbill, crested tit, black and red grouse, snow bunting and ptarmigan, golden eagle, and breeding osprey. Along thousands of miles of coastline, you will see colonies of seabirds clustered in cliffs—gannets, puffins, guillemots, razorbills, and kittiwakes.

There's extraordinary birding to be found in Scotland, wherever you may be, but for some of the best birding in Europe, head to Shetland. This archipelago of over one hundred islands is in the northernmost section of the British Isles. Closer to Norway than to the Scottish mainland, Shetland is one of the most interesting natural environments in the world, and opportunities for spectacular bird sightings are common here. Shetland is famous for its colonies of seabirds and the number and variety of rare migrants it attracts in the spring and autumn. About one-

Taking flight over the Highlands

fifth of the total puffin population of Scotland, approximately 125,000 pairs, breeds in Shetland. Throughout the isles you'll come across throngs of Arctic terns and both species of skuas, as well as black guillemots, gannets, shags, and Storm and Leach's petrels. Rare birds turn up on all the islands, but the best areas to spot them are in the central and south mainland. Print out a checklist at http://www.wildlife.shetland.co.uk before you venture out to these wild northern areas.

At Isle of May National Nature Reserve, in the mouth of the Firth of Forth, you'll see thousands of puffins in May and June. But if you don't have enough time for a northern adventure, visit Bass Rock, a dramatic volcanic plug only one hour from Edinburgh. Take a boat trip here and gaze at the gannets nesting on cliffs a thousand feet high. For a one-of-a-kind "armchair birding" experience, visit the National Seabird Centre in North Berwick. Here, you can watch seabirds such as gannets and puffins up close—or stay inside and watch live videos, using remote control television cameras, from the nearby seabird colonies.

The estuaries and salt marshes of the Solway Firth, in southwest Scotland, are feeding and roosting grounds for many thousands of wintering wildfowl. Visit the Caerlaverock National Nature Reserve, south of Dumfries, a site for wintering waterfowl and waders. And on the coast north of Aberdeen, stop at the Forvie National Nature Reserve, a smaller estuary that is home to the largest breeding population of eider duck in Britain.

WEST VIRGINIA

WITH MORE THAN 80,000 acres of state parks and 100,000 acres of forests, West Virginia offers a natural, peaceful setting for watching its native wildlife.

From the Potomac Highlands in the northeast to the New River Valley in the south, West Virginia is home to hundreds of species of birds that find sanctuary amid its breathtaking mountains, valleys, forests, lakes, and streams.

A variety of community groups, as well as educational programs at most state parks, is available to help both the casual observer or serious watcher plan an adventure to remember.

From wood and waterfowl to raptors, osprey and so much more, the wonders of wildlife await in Wild and Wonderful West Virginia. For more information and a free travel guide, call 1-800-CALL WVA or check out www.callwva.com.

Delta Queen Cruises

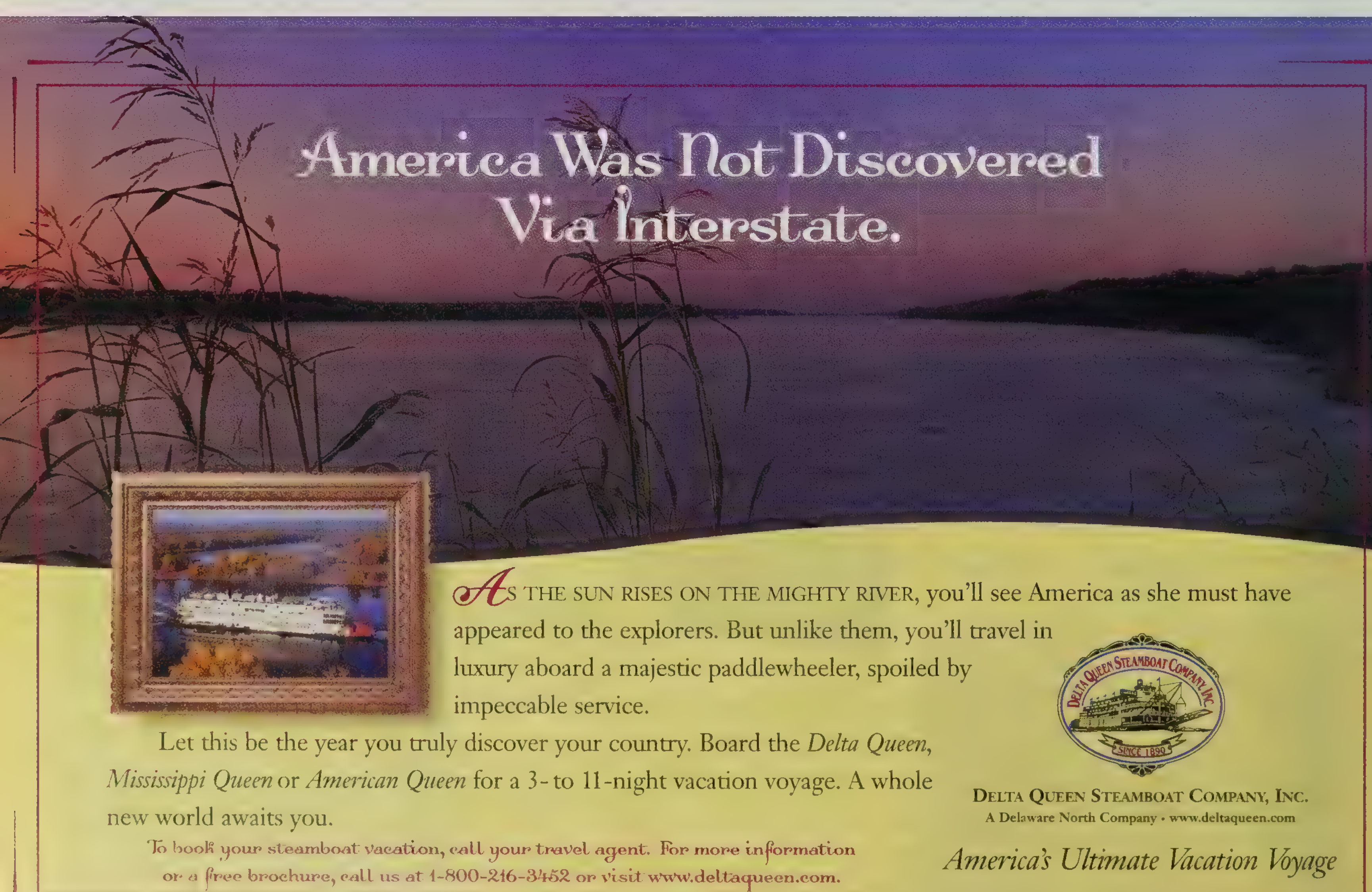
TAKE A TRIP BACK INTO TIME when you go Steamboatin' with the Delta Queen Steamboat Company.

This cruise company specializes in nostalgic river cruise vacations that transport passengers back to an earlier, genteel time. From the time you board one of the company's three impeccably preserved steamboats, you will find yourself in the refined milieu of the Great Steamboat Era.

Delta Queen's three steamboats are the *Delta Queen*, so grand that it is a National Historic Landmark; the magnificent *Mississippi Queen*, with its Victorian ambience and décor; and the majestic *American Queen*, the world's largest steamboat. These

three authentic steam paddle-wheelers offer 3- to 11-night cruises on America's great inland waterways.

The *Delta Queen* has been hostess to three presidents, a princess, and too many dignitaries to count. As America's oldest overnight paddlewheeler, she is in a class of her own. This wonderfully refurbished boat offers the comforts of today with the style of yesterday: Tiffany-style lamps; the warm, polished wood of antique furnishings; gleaming brass fittings; a Siamese ironwood floor; and a magnificent Grand Staircase crowned by a crystal chandelier. On the *Mississippi Queen*, old-time banjos and a calliope belt out favorites from long ago as passengers explore six decks worth of elegance. And on the *American Queen*, you can gaze out the floor-to-ceiling windows of the two-story dining room and delight in entertainment in a Grand Saloon so elegant it is reminiscent of a small river town's opera house. Whatever cruise you choose, you will benefit from Delta Queen's commitment to showcase the history, heritage, and magnificent scenery that abounds throughout America's heartland.



Canada. Discover Our True Nature.

WITH ALMOST 700 BIRD species, Canada is a natural destination for avid birders. From Newfoundland and Labrador to Yukon, from British Columbia to Nova Scotia, the abundance of authentic wilderness offers unparalleled bird watching.

In Newfoundland and Labrador, discover a land of rugged, intense beauty that is home to no less than forty million seabirds. Don't miss the chubby, colorful puffins of the Witless Bay Ecological Reserve or the seven million storm petrels found on Baccalieu Island. Farther east, Nova Scotia alone has 429 bird species. In the mud flats of the Bay of Fundy, you'll see large roosts of shorebirds—plovers, yellowlegs, godwits, curlews, and phalaropes—at high tide.

Out west, visit British Columbia, and hike through the Brackenrale Eagle Reserve—home to one of the highest concentrations of bald eagles in the world. There's no overstating the awe inspired by the sight of up to 3,700 eagles on the wing. Then, stop by Saskatchewan, one of the best places in the world to observe the elegant whooping cranes' 2,500-mile migration.

Be sure to treat yourself to one of our first-class hotels, spas or resorts, and indulge in Canada's unique and delightful cuisine.

For more information, visit www.travelcanada.ca/bird.

Belize Lodge & Excursions

REMARKABLE AS it may seem, more than two-thirds of the country of Belize is still forested, and almost half of it is protected, making it a haven for 540 species of birds. Birds are so plentiful that it's not unusual for even a casual birder to spot 50 different species in a single outing.

What better way to see the birds and other remarkable wildlife of Belize than to take an off-the-beaten-path vacation arranged by Belize Lodge & Excursions Limited. This unique ecotourism facility and adventure travel operator will make sure you visit the very best lodges and destinations in Belize following carefully laid-out itineraries. You'll see why tiny Belize, located on the Caribbean, is a favorite destination for those with a passion for natural history.

Stay at the foothills of the Maya Mountains and hike along miles of nature trails. Explore the mysteries of a Maya ruin and a local indigenous village. Or stay deep in the heart of the jungle and embark on an overnight river expedition—you will be awed by some of the last undisturbed lowland tropical rainforest remaining in Central America. Whatever accommodation you choose, Belize Lodge & Excursions will make sure your adventure is exciting and memorable.

Stick-in-the-Mud Science

You'll need your brain and plenty of patience—but not much more—to take the measure of the Earth and its motions.

By Neil deGrasse Tyson

For a century or so, various blends of high technology and clever thinking have driven cosmic discovery. But suppose you have no technology. Suppose all you have in your backyard laboratory is a stick. What can you learn? Plenty.

With patience and careful measurement, you and your stick can glean an outrageous amount of information about our place in the cosmos. It doesn't matter what the stick is made of. And it doesn't matter what color it is. The stick just has to be straight.

Hammer the stick firmly into the ground where you have a clear view of the horizon. Since you're going low-tech, you might as well use a rock for a hammer. Make sure the stick isn't floppy and that it stands up straight. Your caveman laboratory is now ready.

On a clear morning, track the length of the stick's shadow as the Sun rises, crosses the sky, and finally sets. The shadow will start long, get shorter and shorter until the Sun reaches its highest point in the sky, and finally lengthen again until sunset. Collecting data for this experiment is about as exciting as watching the hour hand move on a clock. But since you have no technology, not much else is competing for your attention. Notice that when the shadow is shortest, half the day has passed. At that moment—called local noon—the shadow points due north or due south, depending which side of the equator you're on.

Steve Irvine, *Analemma above Keppel Henge*, May 2000 to May 2001

You've just made a rudimentary sundial. And if you want to sound erudite, you can now call the stick a gnomon (I still prefer "stick"). Note that in the Northern Hemisphere, where civilization began, the stick's shadow will revolve clockwise around the base of the stick as the Sun moves across the sky. Indeed, that's why the hands of a clock turn "clockwise" in the first place.

If you have enough patience and cloudless skies to repeat the exercise 365 times in a row, you will notice that the Sun doesn't rise from day to day at the same spot on the horizon. And on two days a year the shadow of the stick at sunrise points exactly opposite the shadow of the stick at sunset. When that happens, the Sun is rising due east, setting due west, and daylight lasts as long as night. Those two days are the spring and fall equinoxes (from the Latin for "equal night"). On all other days of the year the Sun rises and sets elsewhere on the horizon. So the adage that the Sun always rises in the east and sets in the west was invented by somebody who never paid attention to the sky.

If you're in the Northern Hemisphere while you're tracking the points on the horizon where the Sun rises and sets, you'll see that those spots inch north of the east-west line after the spring equinox, eventually stop, and then inch south for a while. After they cross the east-west line again, the southward inching eventually slows down, stops, and gives way to the northward inching once again. The entire cycle repeats annually.

All the while, the Sun's trajectory is changing. On the summer solstice (Latin for "stationary Sun"), the Sun rises and sets at its northernmost point along the horizon, tracing its highest path across the sky. That makes the solstice the year's longest day, and the stick's noontime shadow on that day the shortest. When the Sun rises and sets at its southernmost point along


NATURAL HISTORY

the horizon, its trajectory across the sky is the lowest, creating the year's longest noontime shadow. What else to call that day but the winter solstice?

For 60 percent of the Earth's surface and about 75 percent of its human inhabitants, the Sun is never, ever directly overhead. For the rest of our planet, a 3,200-mile-wide belt around the equator, the Sun climbs to the zenith only two days a year (OK, just one day a year if you're smack on the tropic of Cancer or the tropic of Capricorn). I'd bet the same person who professed to know where the Sun rises and sets on the horizon also started the adage about the Sun always being directly overhead at high noon.

So far, with a single stick and herculean patience, you have identified the cardinal points on the compass and the four days of the year that mark the change of seasons. Now you need to invent some way to time the interval between one day's local noon and the next. An expensive chronometer would help here, but one or more well-made hourglasses will also do just fine. Either timer will enable you to determine, with great accuracy, how long it takes for the Sun to revolve around the Earth: the solar day. Averaged over the entire year, that time interval is equal to twenty-four hours—exactly—though this doesn't include the leap second added now and then to account for the slowing of the Earth's rotation by the Moon's gravitational tug on Earth's oceans.

Back to you and your stick. We're not done yet. Establish a line of sight from its tip to a spot on the sky, and use your trusty timer to mark the moment a familiar star from a familiar constellation passes by. Then, still using your timer, record how long it takes for the star to realign with the stick from one night to the next. That interval, the sidereal day, lasts twenty-three hours, fifty-six minutes, and four seconds. The almost-four-minute mismatch between the sidereal and solar days forces the Sun to migrate across the patterns of background stars, creating the impression that the Sun visits the stars in one constellation after another throughout the year.

Of course, you can't see stars in the daytime—other than the Sun. But the ones visible near the horizon just after sunset or just before sunrise flank the Sun's position on the sky, and so a sharp observer with a good memory for star patterns can interpolate what patterns lie behind the Sun itself.

Once again taking advantage of your timing device, you can try something different with your stick in the ground. Each day for an entire year, mark where the tip of the stick's shadow falls at noon, as indicated by

The Sun seldom rises due east, and—for most of Earth's inhabitants—it's never, ever directly overhead.

your timer. It turns out that each day's mark will be in a different spot, and by the end of the year you will have traced a figure eight, known to the erudite as an "analemma" [*see photograph on page 32*].

Why? Earth is tilted on its axis by 23.5 degrees from the plane of the solar system. This tilt not only gives rise to the familiar seasons and the wide-ranging daily path of the Sun across the sky, it's also the dominant cause of the figure eight that emerges as the Sun migrates back and forth across the celestial equator throughout the year. Moreover, the Earth's orbit about the Sun is not a perfect circle. According to Kepler's laws of planetary motion, its orbital speed must vary, increasing as we near the Sun and slowing down as we recede. Because the rate of the Earth's rotation remains rock-steady, something has to give: the Sun does not always reach its highest point on the sky at "clock noon." Although the shift is

slow from day to day, the Sun gets there as much as fourteen minutes late at certain times of year. At other times it's as much as sixteen minutes early. On only four days a year—corresponding to the top, the bottom, and the middle crossing of the figure eight—is clock time equal to Sun time. As it happens, the days fall on or about April 15 (no relation to taxes), June 14 (no relation to flags), September 2 (no relation to labor), and December 25 (no relation to Jesus).

Next up, clone yourself and your stick and send your twin due south to a preselected spot far beyond your horizon. Agree in advance that you will both measure the length of your stick shadows at the same time on the same day. If the shadows are the same length, you live on a flat—or a supergigantic—Earth. If the shadows have different lengths, you can use simple geometry to calculate the Earth's circumference.

The astronomer and mathematician Eratosthenes of Cyrene (276–194 B.C.) did just that. Comparing shadow lengths at noon in two Egyptian cities—Syene (now called Aswan) and Alexandria, which he overestimated to be 5,000 stadia apart—Eratosthenes derived a value for Earth's circumference that was within 15 percent of being correct. The word "geometry," in fact, comes from the Greek for "earth measurement."

Although you've now been occupied with sticks and stones for several years, the next experiment will take only about a minute. Use a stone to pound your stick into the ground at an angle other than vertical, so that it resembles a typical stick in the mud. Tie a stone to the end of a thin string and dangle it from the stick's tip. Now you've got a pendulum. Measure the length of the string and then tap the bob to set the pendulum in motion. Count how many times the bob swings in sixty seconds.

The number, you'll find, depends very little on the width of the pendulum's arc, and not at all on the mass of

the bob. The only things that matter are the length of the string and what planet you're on. Working with a relatively simple equation, you can deduce the acceleration of gravity on Earth's surface—which is a direct measure of your weight. On the Moon, with only one-sixth the gravity of Earth, the same pendulum will move much more slowly, executing fewer swings per minute. There's no better way to take the pulse of a planet.

Until now your stick has offered no proof that the Earth itself rotates—only that the Sun and the nighttime stars revolve at regular, predictable intervals. For the next experiment, find a stick more than ten yards long and, once again, pound it into the ground at a tilt. Tie a heavy stone to the end of a long, thin string, and dangle it from the tip. Now, just like last time, set it in motion. The long, thin string and the heavy bob will enable the pendulum to swing unencumbered for hours and hours and hours.

If you carefully track the direction the pendulum swings, and if you're extremely patient, you will notice that the plane of its swing slowly rotates. The most pedagogically useful place to do this experiment is at the geographic North (or, equivalently, South) Pole. At the Poles, the plane of the pendulum's swing makes one full rotation in twenty-four hours—a direct measure of the direction and rotational speed of the Earth beneath it. For all other positions on Earth, except along the equator, the plane still rotates, but more and more slowly as you move from the Poles toward the equator. At the equator the plane of the pendulum does not move at all. Not only does this experiment demonstrate that it's the Earth, not the Sun, that moves, but with the help of a little trigonometry you can also turn the question around and use the time needed for one rotation of the pendulum's plane to determine your latitude on our planet.

The first person to use a pendulum to demonstrate the Earth's rotation was Jean-Bernard-Léon Foucault, a French physicist who surely conducted the last of the truly cheap laboratory experiments. In 1851 he invited his colleagues to "come and see the Earth turn" at the Panthéon in Paris. Today there's a Foucault pendulum in practically every science and technology museum in the world.

Thomas Kellner, *Stonehenge, 33#34,* 2002

Given all that one can learn from a simple stick in the ground, what are we to make of the world's famous prehistoric observatories? From Europe and Asia to Africa and Latin America, a survey of ancient cultures turns up stone monuments that served as low-tech astronomy centers, though it's likely they also doubled as places of worship or embodied other deeply cultural meanings.

On the morning of the summer solstice at Stonehenge, for instance, several of the stones in its concentric circles align precisely with sunrise. Certain other stones align with the extreme rising and setting points of the Moon. Begun in about 3100 B.C. and altered during the next two millennia, Stonehenge incorporates outsize monoliths quarried far from its site on Salisbury Plain in southern England. Eighty or so bluestone pillars, each weighing several tons, came from the Preseli Mountains, roughly 240 miles away. The so-called sarsen stones, each weighing as much as fifty tons, came from Marlborough Downs, twenty miles away.

Much has been written about the cultural and scientific significance of Stonehenge. Historians and casual observers alike are impressed by the astronomical knowledge of these ancient people, as well as by their ability to transport such obdurate materials such long distances. Some fantasy-prone observers are so impressed that they even credit extraterrestrial intervention at the time of construction.

Why the ancient civilizations that built the place did not use the easy, nearby rocks remains a mystery. But the skills and knowledge on display at Stonehenge are not. The major phases of construction took a few hundred years in toto. Perhaps the preplanning took another hundred or so. You can build anything in half a millennium—I don't care how far you have to drag your bricks. Furthermore, the astronomy embodied in Stonehenge is not fundamentally deeper than what can be discovered with a stick in the ground.

Perhaps these ancient observatories perennially impress modern people because modern people have no idea how the Sun, Moon, or stars move. We are too busy watching evening television to care what's going on in the sky. To us, a simple rock alignment based on cosmic patterns looks like an Einsteinian feat. But a truly mysterious civilization would be one that made no cultural or architectural reference to the sky at all.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

We're looking for people to—

Write Children's Books

By Kristi Holl

If you've ever dreamed of writing for children, here's your chance to test that dream. . . and find out if you have the aptitude to make it a reality. If you do, we'll teach you how to crack one of today's most rewarding markets for new writers.

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The tremendous recent success of children's books has made the general public aware of what we've known for years: There's a huge market out there. And there's a growing need for new writers trained to create the nearly $2 billion of children's books purchased every year. . . plus the stories and articles needed by more than 600 publishers of magazines for and about children and teenagers.

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Fifteen years ago, I was where you may be now. My occasional thoughts of writing had been pushed down by self-doubt, and I didn't know where to turn for help. Then, on an impulse, I sent for the Institute's free writing aptitude test and it turned out to be the spark I needed. I took their course and my wonderful author-instructor helped me to discover, step-by-step, that my everyday life—probably not much different from yours—was an endless creative resource for my writing!

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My fellow instructors—all of them professional writers or editors—work with their students the same way I work with mine: When you've completed an assignment on your own schedule, at your own pace, you send it to me. I read it and reread it to make sure I get everything out of it that you've put into it. Then I edit it line-by-line and send you a detailed letter explaining my edits. I point out your strengths and show you how to shore up your weaknesses. Between your pushing and my pulling, you learn how to write—and how to market what you write.

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"Before this, I didn't know if my work was typical or bland, or if there was even a spark of life in it," writes Kate Spanks, Maple Ridge, BC. "I now have over 30 articles published. . .."

". . .a little bird. . .has just been given freedom"

This course has helped me more than I can say," says Jody Drueding, Boston, MA. "It's as if a little bird that was locked up inside of me has just been given the freedom of the garden."

". . .I was attracted by the fact that you require an aptitude test," says Nikki Arko, Raton, NM. "Other schools sign you up as long as you have the money to pay, regardless of talent or potential."

"I'd take the course again in a heartbeat!"

"My most recent success has been the publication of the novel I started for my last Institute assignment," writes Jennifer Jones, Homer, NY. "Thank you for giving me the life I longed for."

"I'd take the course again in a heartbeat!", says Tonya Tingey, Woodruff, UT. "It made my dream a reality."

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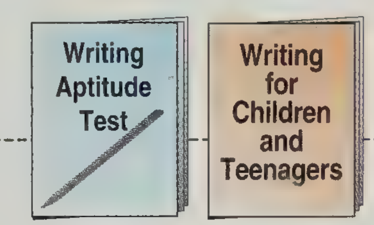
Kristi Holl, a graduate of our course, has published 24 books and more than 100 stories and articles. She is now an instructor at the Institute.



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Open Wide (and Fast)

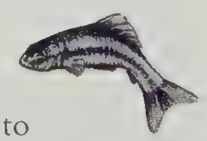
The law of physics that propels rockets into space enables an Australian turtle to catch a darting fish.

By Adam Summers
Illustrations by Shawn Gould

Slow and steady might win races for tortoises, but it's not clear that the same strategy would work for a pond turtle ambushing its prey. Imagine one of these torpid reptiles trying to hide its awkward shell from a school of minnows: The turtle crouches warily behind a tuft of vegetation. Suddenly . . . long pause . . . the creature lumbers out from its blind, racing along at inches per second in hot (but clumsy) pursuit of its meal. Favorable comparisons between the turtle and, say, a cheetah lying in wait for a Thomson's gazelle do not spring to mind.

Yet—who'd have thunk it?—several turtles make fine ambush predators. The massive alligator snapper, for one, lures fish into its gaping mouth by twitching the tip of its tongue. Another, the Australian snake-necked turtle, grabs its prey with a quick, serpentine strike. The basic mechanics of its strike are both surprising and surprisingly effective.

The Australian snake-necked turtle *(Chelodina longicollis)* is a member of the suborder Pleurodira, a group of turtles limited to the Southern Hemisphere. Many, the Australian snake-neck included, have far longer necks than their cousins, the Cryptodira. One consequence is that a pleurodire cannot retract its head into its shell by bending its neck up and back; instead, the animal must fold its neck sideways into a deep hollow at the front of the shell. But the long neck also enables the turtle to ambush fishes and tadpoles by shooting its head far forward, almost as far as the entire length of its body.



The turtle's head lies at the end of eight neck vertebrae, which are connected to the body by more than fifty muscles. Given such a complex anatomy, one might think that making a high-speed stab at a fish would call for neuromuscular coordination worthy of Barry Bonds hitting a slider. Not so. In fact, as Peter Aerts, a biologist at the University of Antwerp in Belgium and his colleagues have found, the turtle's rapid capture of prey paradoxically requires far less motor control than does a slow, deliberate bite.

How can the stimulation of dozens of muscles in the complicated multijoint system that constitutes the turtle's neck be coordinated in just the right sequence and with just the right timing for the turtle to get its head to its quarry? Consider, as Aerts did, a folding carpenter's rule with ten segments (representing the head, the eight vertebrae, and the body). Starting from a relaxed S-bend, similar to the usual starting position for the turtle, imagine extending the "head" of the rule in a straight line towards a target by adjusting each of the hinges a bit at a time. Impossible? No, but certainly extremely tedious.

A turtle relying on vertebral muscles to extend its neck confronts the same problem—and being methodical is no way to catch a darting little fish. But, as Aerts points out, the rule can be quickly and accurately extended to the target if the head is grasped and yanked in the desired direction. The joints move where they will; perhaps they each follow different bending patterns with each new extension. But the head gets where it's going without wavering off course.

What a handy solution to the problem of extending the carpenter's rule! Yet, at first blush, it appears irrelevant to the case of the turtle. After all, why would a hunted fish yank a turtle's head anywhere—when it probably wouldn't want to touch that head with a ten-foot pole? But nature has other ways to get the job done, as Aerts and his colleagues Johan van Damme and Anthony Herrel realized. With a little help from Sir Isaac Newton, a turtle can actually *pull* its own head towards its prey.

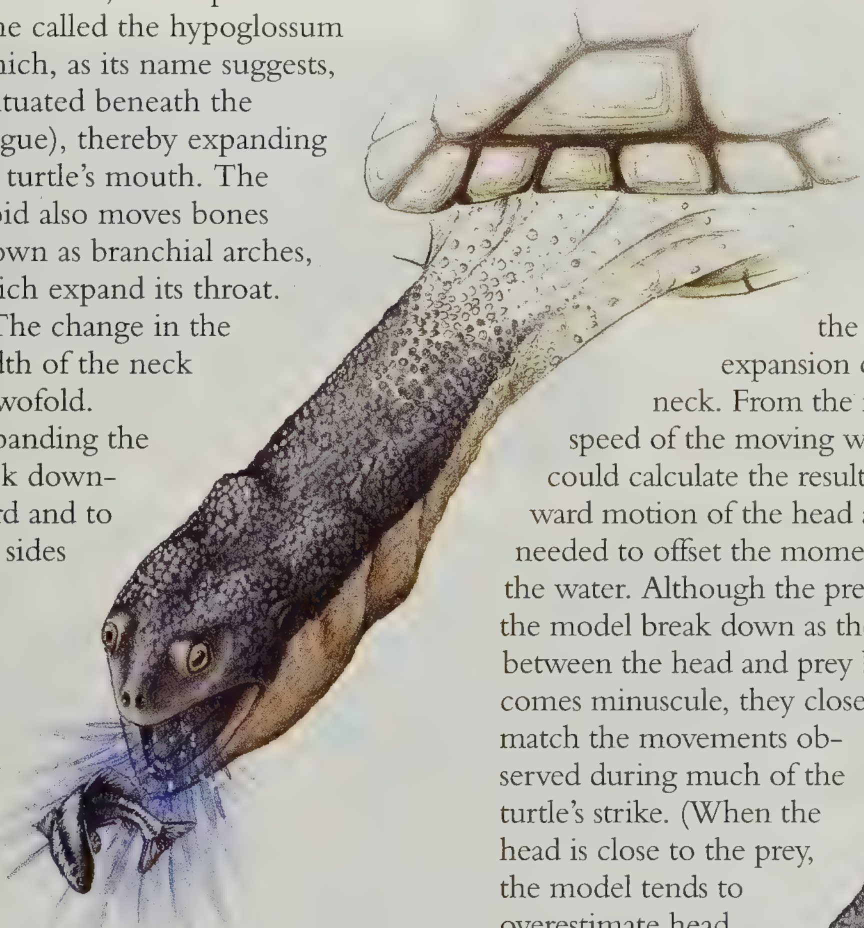
If that action seems about as likely as a fish committing suicide, recall Newton's third law: for every action there is an equal and opposite reaction. Here the action is a sudden suction, caused when the turtle floods its mouth and throat with a large volume of water. The linchpin of the system for controlling this action is a bony structure called the hyoid apparatus. In most vertebrates the hyoid supports the tongue, as it does in the snake-necked turtle. But in the snake-neck, it also pushes down a bone called the hypoglossum (which, as its name suggests, is situated beneath the tongue), thereby expanding the turtle's mouth. The hyoid also moves bones known as branchial arches, which expand its throat.

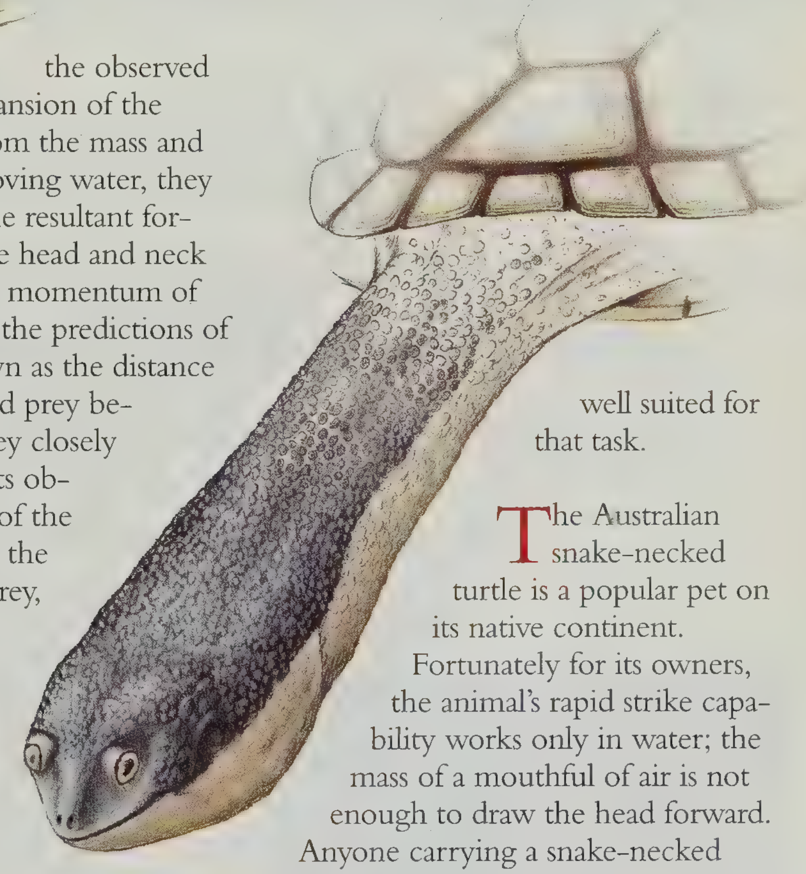
The change in the width of the neck is twofold. Expanding the neck downward and to the sides causes water to rush into the mouth and flow down the throat. The Newtonian reaction to the rearward-rushing water then snaps the head forward almost instantaneously (the acceleration of the head can be more than four times the acceleration of gravity). The effect is almost exactly the opposite of what happens when an unattended garden hose is turned on: the straight hose, reacting like a rocket to the water shooting out its end, writhes into S-curves. In the case of the turtle, an S-curved neck straightens when water is sucked inside.

To bolster their hypothesis, the Belgian biologists developed a mathematical model that derives the rearward-rushing volume of water from the observed expansion of the neck. From the mass and speed of the moving water, they could calculate the resultant forward motion of the head and neck needed to offset the momentum of the water. Although the predictions of the model break down as the distance between the head and prey becomes minuscule, they closely match the movements observed during much of the turtle's strike. (When the head is close to the prey, the model tends to overestimate head movement because it does not compensate for the neck's connective tissue and muscles, which absorb some of the kinetic energy as they stretch.)

To further rule out the possibility that vertebral muscles might be controlling the strike, the biologists implanted fine wire electrodes into the animal's neck muscles to detect the activity of each muscle. Sure enough, as one would expect if the Newtonian explanation is correct, the vertebral muscles were largely quiet during extension, whereas the muscles of the hyoid were firing.

One consequence of the "head pull" mechanism is that the turtle must aim its head at the target in the water before opening its mouth and throat. Indeed, early in the strike, before the turtle's head accelerates, the turtle takes aim at the prey animal—using its vertebral muscles. It turns out that the muscles of the vertebral column are well suited for that task.





The Australian snake-necked turtle is a popular pet on its native continent. Fortunately for its owners, the animal's rapid strike capability works only in water; the mass of a mouthful of air is not enough to draw the head forward. Anyone carrying a snake-necked turtle is safe from a speedy bite.

That's not to say that slow and steady can't still win a race—or deliver a bite. If you're handling such a turtle, keep a wary eye on its slow-moving head. Like the careless hare, you'd surely hate to be caught napping.

If the airplane won't come to the hangar, bring the hangar to the airplane. The Australian snake-necked turtle catches its prey by opening its mouth—the movement of muscles and bones in its head and neck rapidly expands its throat, which instantaneously fills with water. The momentum of inrushing fluid, by virtue of the third law of motion, jerks the turtle's head forward and, assuming the turtle has aimed correctly, directly at the fish.

Adam Summers (asummers@uci.edu) is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.

Middleton Evans

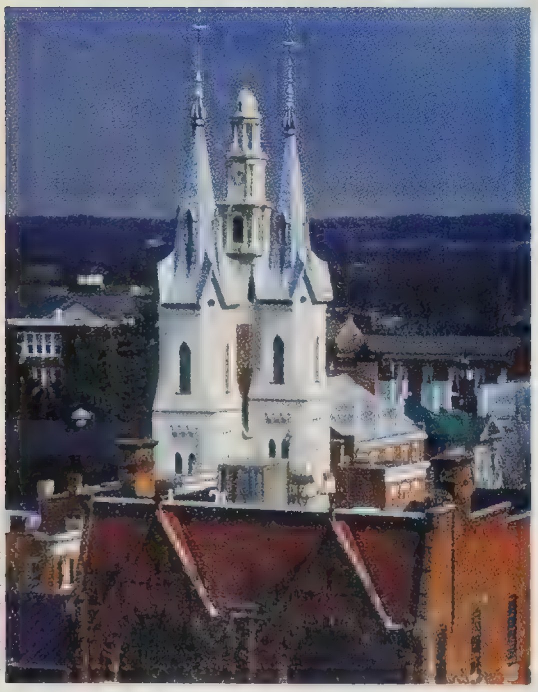
Left: Blackwater National Wildlife Refuge; below: Calvert Cliffs; bottom left: Clustered spires in Frederick

Dan Breitenbach

Maryland

The Land Between Tide and Time

From the shores of the Chesapeake Bay and the Atlantic Ocean to the peaks of the majestic Allegheny Mountains, Maryland is a state of natural wonders.



Middleton Evans

PADDLE THROUGH THE FERtile marshes of the lower Chesapeake as ducks, geese, eagles, and a swirl of birds soar above you. Bicycle on trails that meander through the unspoiled forests of western Maryland, or hike on the Appalachian Trail itself. Cast a line for blue marlin, brook trout, smallmouth bass, or striped bass ("rockfish" to the locals). Hunt for fossils along a shoreline of towering cliffs or prowl for owls on a night hike.

Looking for an adventure in the great outdoors? Visit Maryland's Western Region, nestled in the Appalachian Mountains. Here, you may climb the state's highest mountain, swim in Deep Creek Lake, discover a waterfall, do a little fishing, or brave whitewater rapids.

If you're a history buff, head to the Capital Region, where you'll find Frederick, Montgomery, and Prince George's Counties. Just outside the nation's capital, these counties offer the best of urban sophistication and the tranquility of rural life. Rolling farmlands, covered bridges, and vineyards mark the countryside. And you'll find a wealth of historic sites—from Civil War battlefields to the spectacular Chesapeake and Ohio Canal to fine colonial homes. Visit an aviation museum that celebrates the nation's beginning of aviation, then soar above of the ground

Middleton Evans

at a state-of-the art amusement park, before heading to the Goddard Space Center for an out of this world view of space.

In Central Maryland, colonial history complements maritime heritage. Annapolis, America's sailing capital, hasn't changed much since it became Maryland's capital city in 1695. Today it has more eighteenth-century buildings than any other city in the U.S. It's also home to the U.S. Naval Academy and a center of boating and water sports, including fishing, crabbing, sailing, and swimming.

Historic fishing villages, picturesque small towns, first-class boating, a traditional lifestyle anchored in the Tidewater…the banks of the Patuxent and Potomac Rivers and the shores of the Chesapeake Bay….In Calvert, Charles, and St. Mary's Counties, you'll discover first-hand why Southern Maryland Is Fun. Birders flock to this region to gaze at bald eagles, great blue herons, and more than 300 other species of birds. And after a satisfying day of bird-watching, treat yourself to a scrumptious meal of Maryland's famous blue crabs, oysters, or a freshly caught fish.

On the Eastern Shore, enjoy the splendors of the Chesapeake Bay in the counties of Dorchester, Worcester, Talbot, and Queen Anne's. On the fringes of the bay, fragile marshes and winding waterways are teeming with birds and wildlife. Three of the nation's endangered species are here: the bald eagle, the Delmarva fox squirrel, and the peregrine falcon. Canoe through creeks and rivers, explore historic towns, hike through marshes and woodlands, fish and crab on the Bay—the unspoiled beauty of the area is all around you. Don't miss the natural barrier island of Assateague, one of the state's treasures, and its legendary ponies.

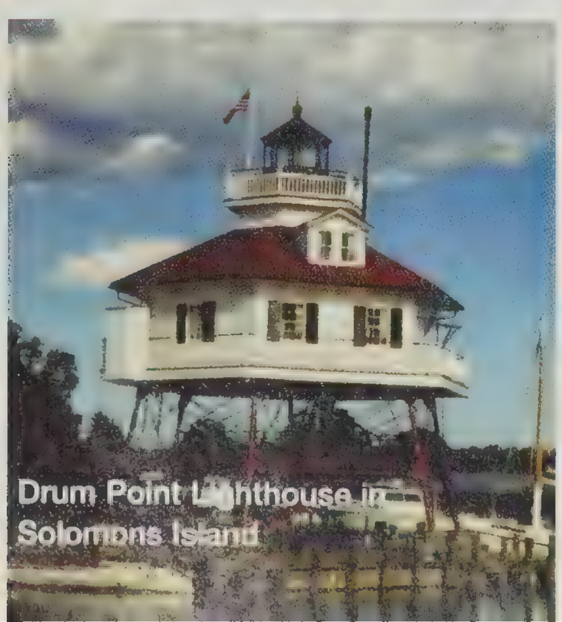
Wherever you decide to go, Maryland will amaze you with all there is to see and do.


The State Capitol at Annapolis

AAACCVB


Historic London Town and Gardens

AAACCVB


Drum Point Lighthouse in Solomons Island

Annapolis/Anne Arundel County

ANNAPOLIS/ANNE ARUNDEL County brings you the best of Maryland's colonial history and maritime heritage. Fronting the shores of the Chesapeake Bay, the county is a center of boating and water sports, including fishing, crabbing, sailing, and swimming. Annapolis, Maryland's capital city and America's sailing capital, has more eighteenth-century buildings and houses than any other city in the U.S. It's also the home of the U.S. Naval Academy (410-263-6933), founded in 1845. Stop at the Armel-Leftwich Visitor Center for a map of the facilities, and don't miss the model ships and history exhibits at the Academy's Museum. If you prefer the countryside, drive along the rural western shore of the Chesapeake Bay, past fishing villages and farms dating from the colonial era, to the "lost" town of London, unearthed in the 1990s.

Calvert County

IN THIS SOUTHERN MARYLAND county, you can take a cruise around Solomons Island, a historic fishing village where the Patuxent River meets the Chesapeake Bay. You can hunt for more than 600 species of fossils on the open beaches at Calvert Cliffs State Park—majestic cliffs, formed more than 15 million years ago, that dominate the Chesapeake Bay. Walk on the elevated boardwalk through the primeval beauty of Battle Creek Cypress Swamp in Prince Frederick, the northernmost naturally occurring stand of bald cypress in America. Visit the picturesque towns of Chesapeake Beach and North Beach. Here you'll find the Chesapeake Beach Railway Museum and the largest fleet of charterboats in the state. When you visit Calvert County, you'll discover why Southern Maryland Is Fun.

Charles County

LESS THAN AN HOUR FROM Washington, D.C. and Annapolis, Charles County is a haven for nature lovers and history buffs on southern Maryland's coastal plain. Enjoy first-class fishing, 150 miles of spectacular shoreline, beautiful forests, and many lakes, ponds, and extensive wetlands.

The county's abundant undeveloped areas support a dense population of bald eagles and 321 other bird species. Every spring for the past fifty years, nearly 1,500 great blue herons have nested in the treetops of Nanjemoy Creek Great Blue Heron Sanctuary. This creek, popular with fishermen, also is a good spot to sight ospreys and bald eagles.

The Chicamuxen Wildlife Management Area (301-743-5161), tucked away on a peninsula, harbors rare and endangered species, such as the Louisiana thrush, on about twenty acres of wetlands. Purse State Park (301-743-7613), a ninety-acre reserve of gently rolling hills, woods, and marshlands, is the perfect site for fossil hunting. And Cobb Island, bordered by the Potomac and Wicomico Rivers, lures birdwatchers as well as fishing, boating, and seafood lovers.

History buffs won't want to miss the Dr. Samuel A. Mudd House (301-645-6870) in Waldorf, home to the country doctor who set the leg of John Wilkes Booth, President Lincoln's assassin, unwittingly helping him to escape to Virginia. Costumed guides now take visitors around the early Victorian frame farmhouse, dating to about 1754 and furnished with original pieces. Also a must-see is the small town of Benedict, the only spot in the United States where foreign troops have invaded our shores. During the War of 1812, British forces landed in Benedict, marched to Washington, D.C., and burned the city.

Dorchester County

DORCHESTER COUNTY IS THE Heart of Chesapeake Country. Marshes and waterways are filled with wildlife and birds, and quaint watermen's villages are sprinkled through the "Cape Cod of the South." The port town of Cambridge, founded in 1684, is lined with historic homes and museums, including the Brannock Maritime Museum, with exhibits on Chesapeake Bay history. Outside of Cambridge, the Dorchester Heritage Museum has exhibits on aviation, archaeology, and local history,

USFWS

and the Richardson Museum focuses on the Bay's long heritage of wooden boat building. Also nearby is the Spocott Windmill, the only post windmill in Maryland, which still grinds flour on special occasions. Blackwater National Wildlife Refuge, just south of Cambridge, is an important nesting and feeding area for three of the nation's endangered species: the bald eagle, the Delmarva fox squirrel, and the peregrine falcon. And at the Harriet Tubman Museum, learn about the famous woman who helped slaves escape to freedom on the Underground Railroad.

The law offices of
Francis Scott Key in Frederick

Tourism Council of Frederick Co.

Frederick County

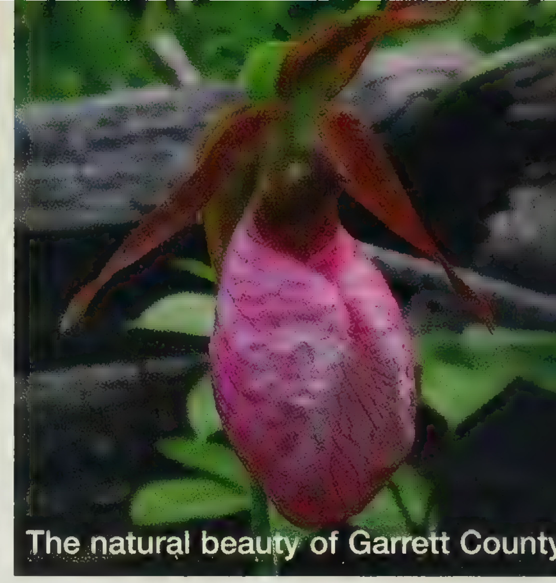
NESTLED IN THE APPALACHIAN Mountains and Piedmont Plateau, Frederick County has more farms than any other county in Maryland. Vineyards and covered bridges dot this county, and the largest water garden in the U.S., the Lilypons Water Gardens, is in Buckeystown. The county also is a center of Civil War history sites, including the Monocacy National Battlefield, the site of the 1864 battle that played a pivotal role in defending Washington D.C. The Barbara Fritchie House and Museum is a replica of the house where 96-year-old Fritchie reportedly confronted General Stonewall Jackson when Confederate forces marched into Frederick in early September 1862.

Garrett County

IN THE MOUNTAINS OF WESTERN Maryland, the Deep Creek Lake Area offers visitors recreation and relaxation in 90,000 acres of lakes, forests, rivers, and parkland.

From the high adventure of whitewater sports on the Youghiogheny and Savage rivers to peaceful paddling on lakes and reservoirs, there is something for everyone.

Eco-tourism and nature tourism opportunities abound, with guided excursions and rental equipment available for hiking, birding, mountain biking, canoeing, rafting, or kayaking.



The natural beauty of Garrett County

This rural area is sparsely populated — only thirteen traffic signals in the entire county. The small towns reflect a quieter time: neighbors still gather in community parks for picnics on the 4th of July and caroling at Christmas. Shops and festivals feature the craftsmanship of Allegheny Mountain artisans and the elegant simplicity of Amish woodworking.

Seneca Creek State Park in Montgomery County

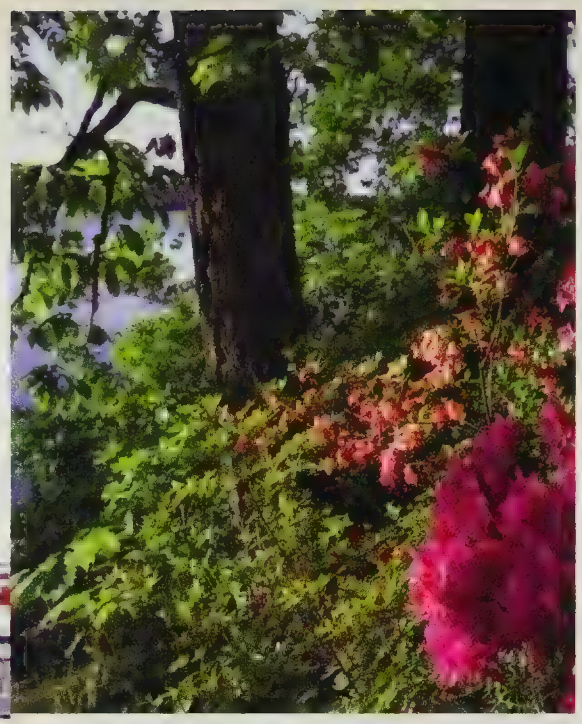
Where the National Road crossed the northern part of the county in the 1800s, inns and taverns were built to accommodate travelers. Some of these still welcome visitors seeking lodging or a home-cooked meal.

At the end of the nineteenth century, the B&O railroad brought the wealthy and powerful from "down east" to vacation in the cool mountain summers. Many ornate Victorian "cottages" remain in the Mountain Lake Park area.

Montgomery County

JUST OUTSIDE OF WASHINGTON, D.C., Montgomery County is not your ordinary suburb. It offers visitors the best of urban sophistication and country leisure, from museums and galleries to theaters, historic sites, and pristine parks. Start your exploration with a visit to Glen Echo, a former amusement park that now is a year-round center of dance, theater, and the arts. The park includes the Clara Barton National Historic Site (301-492-6245), which commemorates the life of the founder of the American Red Cross. Then explore the nearby Chesapeake and Ohio (C & O) Canal National Historic Park, near the Potomac River. The canal was operated from 1828 to 1924, primarily for hauling coal, and hundreds of original structures, including locks, lock houses, and aqueducts, remain. Plan a hike or bike tour along the canal's towpath, which provides a nearly level, continuous trail through the spectacular scenery of the Potomac River Valley.

If you'd rather be fishing, head to Little Seneca Lake in Black Hill Regional Park, just north of Germantown, where you might hook some largemouth bass, tiger musky, crappie, catfish, and several types of sunfish. Rent a rowboat or canoe, take a ride on a pontoon boat, or find a spot in the fishing pier. Hike,



Right: Brighton in Montgomery County; below: Maryland's famous crabs

horseback, or mountain bike through the miles of trails that meander through the quiet forests of this vast park. After a day in the outdoors, treat yourself to a feature at the Olney Theatre Center (301-924-3400), presenting the musical satire *Mainstage* through March 30th.

Prince George's County

BORDERING WASHINGTON, D.C. and a mere thirty-seven miles from Baltimore, Prince George's County offers a range of historic, cultural, and popular tourist sites.

Tour historic homes such as Darnall's Chance House Museum (301-952-8010) in Upper Marlboro, one of Maryland's oldest buildings, dating to 1704; the Montpelier Mansion and Cultural Arts Center (301-953-1376) in Laurel, a fine eighteenth-century Georgian house that was a haunt of George and Martha Washington's; the Marietta House Museum (301-464-5291) in Glenn Date, a plantation home from circa 1813; and Riversdale (301-864-0420) in Riverdale Park, built between 1801 and 1807 and patterned after an eighteenth-century Belgian mansion.

Aviation fans won't want to miss the free tour of the Paul E. Garber Preservation, Restoration, and Storage Facility (reserve a tour at 202-357-1400), where aircraft are restored before they are displayed at the Smithsonian's Air and Space Museum; the College Park Aviation Museum (301-864-6029); or the Airmen Memorial Museum (800-638-0594) in Suitland, honoring leaders in aviation.

Schedule a visit at NASA's Goddard Space Flight Center and Museum (301-286-8981) in Greenbelt, the major U.S. laboratory for developing and operating unmanned scientific spacecraft. On March 18th, you can participate in *Goddard's Sun-Earth Day 2003: Live From the Aurora*, and learn about the sun, its structure, and processes.

If you have children, don't miss Prince George's most popular tourist attraction: Six Flags America (301-249-1500). The theme park features an exciting collection of roller coasters, including the new Batwing, where you fly face down through corkscrews and twists.

Queen Anne's County

IN LOVELY QUEEN ANNE'S COUNTY, on the scenic Eastern Shore of the Chesapeake Bay, enjoy a succulent crab or oyster dinner beside a bustling marina, fish and crab on the Bay, boat through wandering rivers, bicycle through historic and picturesque small towns, and hike through marshes and woodlands on the Cross Island Trail.

Start your visit on Kent Island, just across the Chesapeake Bay Bridge. Established as a trading post in 1631, the island is the oldest settlement in Maryland. In Stevensville, the island's largest town, visit the restored Stevensville Train Depot and Christ Church, home to Maryland's oldest congregation, founded in 1631.

Matapeake State Park, on the island's western shore, offers views of the Bay Bridge, boat ramps, and a 900-foot-long fishing pier. Terrapin Beach Nature Park, off MD 18, includes a one-mile nature trail, pond, two observation blinds, and a boardwalk to the Chesapeake Bay.

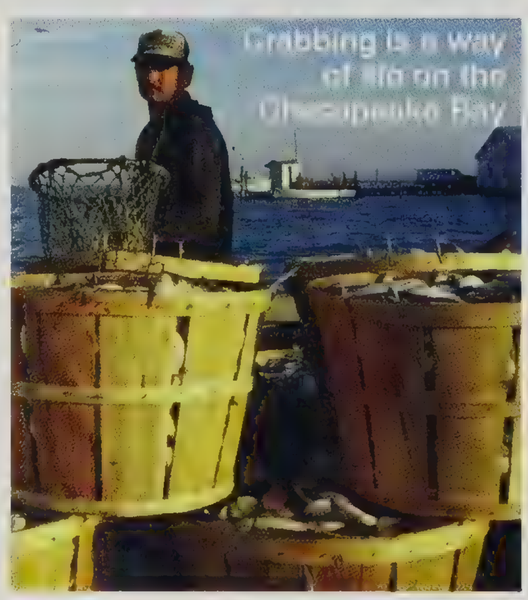
Just east of the island, in Grasonville, the Chesapeake Bay Environmental Center, operated by the Wildfowl Trust of North America, is a 500-acre sanctuary with trails around six waterfowl ponds, each representing a different wetland habitat. You may see deer, red fox, herons, swans, turtles, geese, and many species of ducks and other migratory birds traveling north and south on the Atlantic Flyway. The visitor center has a large picture window overlooking a waterfowl pond, hands-on exhibits for children, and an aquarium featuring creatures from the Chesapeake Bay.

The sixty-acre lake at Tuckahoe State Park, six miles north of the town of Queen Anne, is a haven for boaters and anglers. Tuckahoe Creek meanders through the park's wooded marshlands, and the Adkins Arboretum is home to native Maryland trees and plants.

Tidal inlet along the Patuxent River

St. Mary's County

SHAPED BY THE CHESAPEAKE BAY and its mighty tributaries, the Patuxent and Potomac Rivers, St. Mary's County lies on a verdant peninsula that has fostered a traditional lifestyle anchored in the natural bounty of the Tidewater. Historic sites abound, including St. Mary's City, the state's colonial capital and its premier oudoor living history museum and archaeological park. The tidal landscape of creeks and tributaries offers great opportunities for canoeing and kayacking, and here, the waterman's way of life still centers on the seasonal harvest of crabs and oysters—available for sampling at crabhouses and waterside eateries throughout the county.



Crabbing is a way of life on the Chesapeake Bay

Talbot County

IN TALBOT COUNTY, EXPLORE the unspoiled beauty and historic lore of Maryland's Eastern Shore. Start your tour of this county's charming and historic small towns in the waterfront village of St. Michaels, called "the town that fooled the British" because during the War of 1812 the townspeople hung lanterns in the trees and the British cannons overshot the houses. Here, the Chesapeake Bay Maritime Museum features exhibits on boat building, Chesapeake Bay craft, steamships, and decoy carving. Easton, rated among the Top Ten Best Small Towns in America, is a nostalgic All-American hometown, and Tilghman Island, surrounded by the Chesapeake Bay, is a working watermen's village with excellent fishing (it's home to the last commercial sailing fleet in North America) and fresh seafood.

Take the longest cable-free ferry in the U.S. to Oxford, once a major port and shipbuilding center, or explore picturesque Wye Mills, home to the historic Grist Mill and Museum, the Wye Church, and the Little Red Schoolhouse.

Worcester County

YEAR AFTER YEAR, VISITORS return to the untouched wilderness of Worcester County, where they sail, canoe past majestic cypresses along the Pocomoke River, catch crabs, and fish on the bays, rivers, ocean, and inlets.

Situated on Maryland's lower eastern shore, Worcester was not connected to the mainland until 1952, and it's retained much of its natural beauty. Bald eagles, snowy egrets, great blue herons, otters, muskrat, and deer inhabit the banks of the Pocomoke River. The county is home to the year-round beach resort of Ocean City, the pristine marshlands of Assateague, a natural barrier island, and the quaint historic town of Berlin, with its clusters of charming bed-and-breakfasts, historic inns, and antique stores.

Worcester also offers visitors a unique glimpse into the lives of early African-American pioneers, who settled the county in the mid-1600s. In the Berlin community of Germantown, visit two of the oldest structures from this period: the Comfort Powell House and, right next door, the New Bethel Methodist Church. The Julia A. Purnell Museum in Snow Hill displays the memorabilia of William Julius "Judy" Johnson, who enjoyed a professional baseball career from 1918 to 1939. In Pocomoke City, the Sturgis One Room School Museum, built about one hundred years ago, is an African-American schoolhouse.

Johns Hopkins University Press


USFWS

Heron wading in a marsh

FOUNDED IN 1878 IN BALTIMORE, Johns Hopkins is the oldest university press in continuous operation in North America. Three recent publications are of special interest to naturalists. *Birds of the Mid-Atlantic and Where to Find Them*, by John Rappole, is a comprehensive field guide to bird life in this area, with lists of the best sites to spot specific birds. It provides extensive information about every species: description, identification details, habitat, vocalization, range, seasonal occurrence, and distribution. Each entry is accompanied by a color photograph. *Rock Creek Park*, by Gail Spilsbury, celebrates Rock Creek Park, a resplendent wilderness retreat in Washington, D.C. Spilsbury tells the riveting story of the park's formation and preservation, focusing on how Frederick Law Olmsted Jr. and other visionaries laid down precedents for its preservation. In *The Great Marsh: An Intimate Journey into a Chesapeake Wetland*, David W. Harp's stunning photography and Tom Horton's graceful prose capture the beauty and essence of the disappearing marshland of Blackwater National Wildlife Refuge in Dorchester County. The fertile waters and soggy vegetation are home to ducks, geese, eagles, and dozens of other species. Essays discuss how the endangered marsh functions as a refuge for migrating butterflies and the bogs yield archaeological treasures.

Vietnam's Secret Life

Naturalists exploring the country's mountains and forests are finding that the keys to its extraordinary biodiversity may lie deep in the past.

By Eleanor J. Sterling, Martha M. Hurley, and Raoul H. Bain

Along Vietnam's border with Laos runs the Truong Son range, known to the Laotians as Saiphou Louang and to much of the rest of the world as the Annamites. But the mountains are becoming known—to conservation biologists as well as to everyone else concerned with preserving the world's species—as a region of exceptional biodiversity. In the early 1990s investigators began visiting Vietnam's natural areas in greater numbers than at any time since the beginning of what is known to the people of the region as the Second Indochina War. And the investigators—ecologists, evolutionary biologists, and specialists in a broad spectrum of life-forms—soon confirmed what the local peoples had long known: an astounding array of organisms dwell in the country. For many biologists to this day, entering Vietnam is like entering uncharted territory, an area of vast biological abundance, where new species, it seems, can turn up virtually anywhere you look.

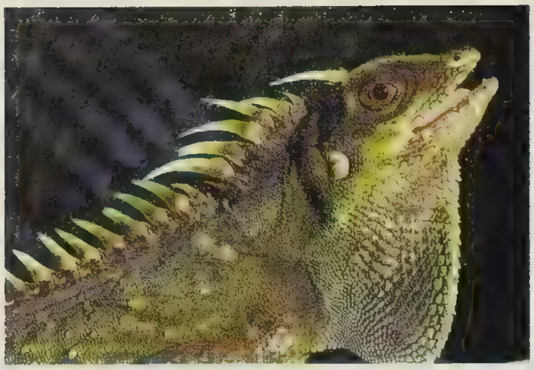
The Sichuan whipping frog has been assigned to the species Polypedates dugritei*—but herpetologists are now realizing that these frogs actually form a group of species, not just one. The several species probably arose when climate change stranded ancestral frog populations on separate mountaintops; the confusion for zoology arose when the climate changed again, first warming and then cooling, enabling the new (but similar-looking) frog species to disperse before they were isolated once more.*

Biologists exploring the Truong Son have discovered—or, importantly, *re*discovered—three previously unrecognized species of muntjac, or barking deer; one species of pig; and one species of rabbit [*see illustrations of the latter two animals on page 53*]. Those findings alone are remarkable; after hundreds of years of systematic biology, who would have thought that large or medium-size mammals would remain to be described? And that list doesn't even include the saola, the sole member of *Pseudoryx,* a genus entirely new to the cattle family. Weighing in at about 220 pounds, the saola is the largest land-dwelling mammal introduced to science since the kouprey, or gray ox, was described in 1937. (That animal ranged through northern Cambodia and adjacent areas of Thailand, Laos, and Vietnam, but may now be extinct.)

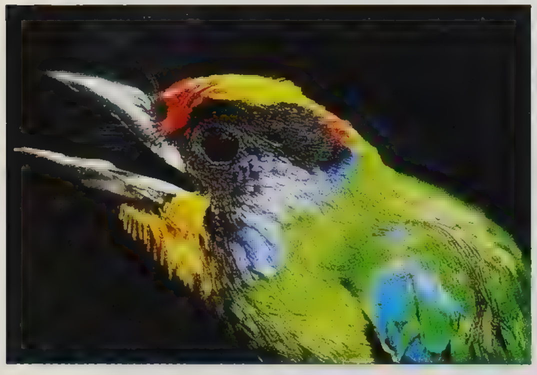
But Vietnam promises more to biologists than just the windfall that is the Truong Son range. Ever since the mid-nineteenth century, up until the beginning of the Second World War, forays by Vietnamese and visiting naturalists had sketched a spotty but telling portrait of the country's biodiversity. More recently, since peace came to Vietnam, further hints of biological abundance have come from collaborations between Vietnamese and foreign investigators.

But only in the past ten years have biologists understood that the newly recognized charismatic megafauna are only the tip of an iceberg of heretofore unknown species that live in the Truong Son as well as in other, primarily montane, areas of Vietnam. Among the organisms new to science (though, again, not to natives of the area) are three

The male red-shanked douc langur (Pygathrix nemaeus nemaeus)*—a stunning arborealist endemic to Southeast Asia—lives in the forests of the northern end of Vietnam's Truong Son Mountains and adjoining lowlands. Because it rarely leaves the trees, climatic change affecting the range of its rainforest home could have forced the monkey into moist, albeit restricted "refuges," leading to the divergence of today's three subspecies of douc: black-, red-, and gray-shanked.*



The green pricklenape lizard (Acanthosaura capra) *is endemic to Indochina. The genus ranges across mainland Southeast Asia as well as on the island of Sumatra, perhaps indicating dispersal during dry periods when the Sunda shelf was exposed; the foothills of the Himalaya prevent the creature from spreading to the west. The lizard prominently displays its dewlap, or fold of loose skin, both to ward off predators and to threaten competitors during courtship.*



Megalaima franklinii auricularis, *a subspecies of the golden-throated barbet, has been observed in only a few parts of the central Truong Son and in southern Laos—a region that has proved a veritable aviary of recently discovered endemic species. As a result, the area is now the focus of conservation efforts.*

The rhinoceros snake (Rhynchophis boulengeri) *ranges across northeastern Vietnam and its small offshore islands, through China's Guangxi region, to the northeast of Vietnam, and China's Hainan Island, but it cannot be found in China's Yunnan Province, northwest of Vietnam. Depressed sea levels during ice ages would have opened the islands to colonization, and the return of warmer weather would have isolated them there, but the inland mountains are still too dry and too cold to be hospitable to these arboreal snakes.*

species of birds, nineteen species of amphibians, sixteen species of reptiles, and, just since the year 2000, at least twenty-nine species of fish and 516 species of invertebrates. And—perhaps just as intriguing—many of the species native to Vietnam do not occur anywhere else: a phenomenon known as endemism.

The ferment of scientific activity in Vietnam in the past decade is a result of several historical developments: the restoration of political stability after decades of war; the recent opening of strategic border areas to scientists; and the reopening of the country to foreign scientific collaborators, such as our group from New York's American Museum of Natural History. Of course, Vietnam's turbulent political history can only explain why so many discoveries are emerging just now. History and politics (aside from the destruction they wreak) have little to say about the country's biodiversity—particularly about why so much of that biodiversity is endemic to it.

The real roots of the region's biodiversity lie in the dynamic interplay over time of geographic, geological, and climatic forces. The heaving of mountains, the shifting courses of rivers, and the expansion and contraction of seas and forests have successively isolated and reunited populations of plants and animals. As new habitats arise and old ones shift, existing organisms can disperse, adapt, or die. Those three options have largely created the unusually complex mosaic of life that exists in the region today.

Mountains and hills wrinkle the vast majority of Vietnam's 127,000 square miles. Major mountain blocks include the highlands in the northeast, the Hoang Lien Son in the northwest (the southeasternmost extension of the Himalaya), and the Truong Son along the border with Laos. A range of forest habitats, each adapted to a different amount of yearly rainfall, blanket the slopes of these mountains.

The seasonality of the rainfall is, in part, a consequence of the monsoon circulation pattern, the dominant climatic feature of southern and eastern Asia for at least the past seven million years. In the winter, strong northeast monsoon winds blow, as air flows from cold, high-pressure areas in Asia along the eastern edge of the Tibetan Plateau toward a hot, low-pressure zone over Australia—a process that brings cold, dry winds to Vietnam. In the summer, air masses move in from the opposite direction, from Australia and the Indian Ocean; passing over Vietnam the air releases moisture picked up along the way, hence the country's summer rains. Those dynamic circulation patterns interact with the terrain and the surrounding ocean to expose Vietnam to widely varying amounts of rainfall.

Temperature and humidity vary with topography; in general, the higher the elevation, the cooler and wetter the climate. The interaction of upland areas with moisture-laden moving air masses creates a "rain shadow": windward slopes wring most of the moisture from the clouds and remain substantially wetter than the leeward slopes. In the Truong Son, for example, the coastal-facing eastern slopes are wetter than those facing west.

Meanwhile, a variety of climates dot Vietnam's interior. Regions without prolonged dry periods support moist evergreen forests; seasonally dry forests—mixtures of evergreen and deciduous trees—grow in areas of more mixed dry and wet periods; and dry deciduous forests range across southwestern regions with expanded dry seasons. In addition, Vietnam also hosts ecosystems as diverse as temperate coniferous forests, mangrove forests, grasslands, and coral reefs.

Geologically speaking, Southeast Asia lies at the interface of three converging continental plates: the Eurasian, Indo-Australian, and Philippine Sea. Continental plates, which are formed

from Earth's rigid, brittle lithosphere, or crust, move gradually across the planet, buoyed by movements from below, in the Earth's mantle. Sometimes the plates break into pieces; an aggregation of continental fragments broke off from the prehistoric supercontinent called Gondwanaland about 400 million years ago. Over the course of the ensuing 200 million years, some pieces of the broken continent migrated north to collide and fuse with Asia at higher latitudes, in the process creating much of what is now Vietnam. The Truong Son range arose during collisions that took place between the late Paleozoic and early Mesozoic Eras, between 340 million and 255 million years ago.

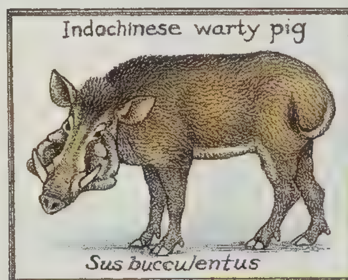
Later, between 55 million and 40 million years ago, what is now the subcontinent of India broke off from Gondwanaland and migrated north, colliding with Eurasia. The fusion of the two landmasses led to a major influx of new species, which dispersed through India and into Southeast Asia. As the collision of India with Asia continued—and it continues to this day—the rising Himalaya and the Tibetan Plateau essentially isolated Southeast Asia from invasions by species from the north and west [see *"The Anguid Odyssey," page 55*].

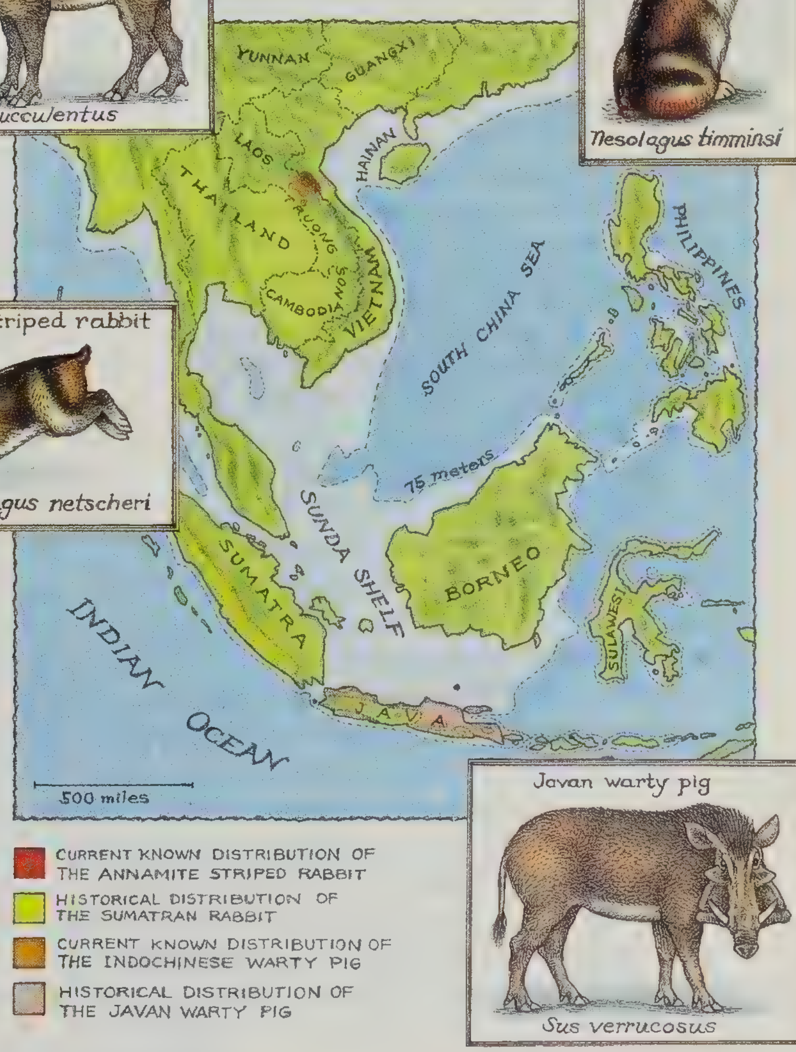
While the Himalaya were rising, Earth's climate began to fluctuate between cool and warm phases. Continental glaciers formed and retreated and, in response, sea levels fell and rose. When sea levels fell, the shallow Sunda continental shelf became exposed (today it lies beneath the seas south of Vietnam). The Sunda shelf linked landmasses that are now separated, forming bridges that joined mainland Southeast Asia to the Sunda Islands—including Borneo, Java, and Sumatra. A mixture of rainforest and grassland, woodland and sedge blanketed the emergent land.

During such glacier-forming cold periods, when much of the Gulf of Thailand and parts of the South China Sea disappeared, the monsoons picked up substantially less moisture than they do today. Seasons became more distinct. Forests previously limited to mountain elevations descended to lower levels, and grasslands proliferated, pushing out lowland evergreen rainforests. The most recent cold period took place about 18,000 years ago, the climax of the last ice age.

In contrast, during the warmer periods between glacial advances the climate became wetter and less seasonal, and the evergreen rainforests expanded, reaching into the higher elevations and latitudes. Sea levels rose, covering the continental shelves and land bridges, splitting up and isolating populations and individual species. Those processes have continued throughout the Cenozoic Era up until what is, geologically speaking, the present day. In Southeast Asia, long-term cycles of isolation and recolonization have been the evolutionary norm.

Those cycles fueled the rise of new species, led to the extinction of others, and, in general, determined the distribution of the present-day flora and fauna of Southeast Asia. Thus the geological and climatic his-





Both the recently described Annamite striped rabbit and the Indochinese warty pig (rediscovered after more than 100 years) are known to range in only a small stretch of the northern Truong Son. Their closest likely relatives, however—the Sumatran striped rabbit and the Javan warty pig, respectively—range more than 1,500 miles away, on the islands for which they are named. Fluctuating sea levels and changing habitats could have spurred multiple cycles of isolation and recolonization across land bridges, eventually leading to the evolution of distinct species. Genetic analyses of the striped rabbits indicate that they became separate species some eight million years ago. (The drawings here are an artist's interpretation of field observations.)

The Cat Ba langur (Trachypithecus poliocephalus) *lives only on Cat Ba, a small rocky island not far off the coast of Vietnam—just the sort of environment to promote the evolution of an endemic species, whether through environmental influences or even through a process such as the founder effect, by which a small group of organisms become distinct from ancestral populations because of the isolation of a limited gene pool. The monkey's numbers were never large, and it is thought to be seriously threatened by the encroachments of tourism. Ironically, tourists could also prove to be its saving grace: they often pay top dollar to see rare primates on minute islands.*

tory of the region can serve biologists as a kind of Rosetta stone, helping them to decode and disentangle the patterns of Vietnam's biodiversity as well as to pinpoint where new species might be found.

Consider, for example, some of the distribution patterns of Vietnamese amphibians and reptiles. Northeastern Vietnam shares more than twenty of these species with China's Hainan Island and Guangxi autonomous region. China's Yunnan Province, however, which borders both Vietnam and Guangxi, shares none of them. Sea-level changes, in concert with climate, help explain the patterns. Low sea levels during the Pleistocene Epoch, beginning 1.8 million years ago, enabled flora and fauna to migrate back and forth from the mainland to Hainan Island. But the drier, cooler climate of Yunnan Province limited the westward dispersal of at least some of the species.

Sea levels far lower than they are today also enabled amphibians and reptiles to travel freely back and forth between the Greater Sunda Islands and mainland Southeast Asia. As a result, the two areas share roughly a fifth of their amphibian and reptile species. In fact, investigators comparing present-day species distributions with measurements of contemporary ocean depths can demonstrate how low sea levels must have fallen during some geological periods. Moving across the sea would have been hard for reptiles and practically impossible for amphibians, whose permeable skin does not tolerate saltwater.

Inland, away from the seas, climate and geography can also play a role in the rise of new species as well as in endemism. Here, however, Vietnam's climatic cycles drove organisms up and down mountains rather than back and forth across land bridges that were later flooded.

For example, when the climate warmed, montane forest communities contracted and moved up the mountain slopes, where the climate was relatively cool. Those contractions could keep forest populations living on separate slopes isolated for substantial periods of time—in some cases, long enough to differentiate into distinct species. Later, when the climate cooled again and the forests expanded downslope, those now-distinct species could disperse throughout the lowlands. If further warming phases pushed the new species back up to high elevations, many might end up populating new, or more widespread, areas than the ones where they originated. The effect, of course, is virtually identical to that of rising and falling sea levels, which led to island endemism. But the mixing of evolutionary lineages and the resultant diversity means zoologists are faced with a tangle that they are only now sorting out.

Bird endemism also seems to follow such a tangled pattern. Montane forests above about 3,000 feet in the Truong Son are rich in songbird diversity, notably in the flycatchers and Old World warblers and related species. Two of the three new bird species described in the central

The male crested argus (Rheinardia ocellata) *has the longest tail feathers of any bird in the world, reaching a maximum length of nearly seventy inches. Two separate regions host the birds: the Truong Son of Vietnam and Laos, and montane areas on the Malay Peninsula. The disjunct range could be a consequence of sea-level changes and variations in forest cover in recent geological times, leaving the species in only these evergreen forest refuges. This photograph was taken using a "camera trap"—a camera attached to a motion detector that can do fieldwork when no one is around.*

Truong Son (the black-crowned barwing, the golden-winged laughingthrush, and the chestnut-eared laughingthrush) are endemic to the area. Biologists have recognized eleven endemic subspecies of babblers there as well. These discoveries have led the conservation organization Bird-Life International to designate this region of the Truong Son a high priority for bird conservation.

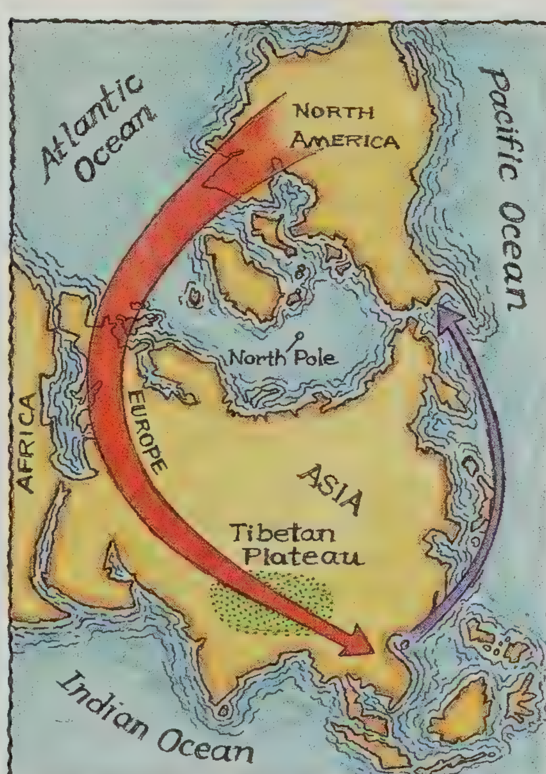
The patterns of endemism and speciation observed in Vietnam are set in motion when the separated populations become trapped by some kind of barrier that develops between them. But that barrier need not be elevation, or a land bridge that has been flooded. In the Truong Son another kind of barrier has arisen, in the form of a moist refuge surrounded by a drier environment.

As we noted earlier, the Truong Son act as a barrier to the monsoon winds, giving rise to high rainfall and a reduced dry season on the eastern slopes. As a result, moist evergreen forests have grown historically at all elevations to the east of the main ridge (though today much of the land at lower elevations is deforested). In contrast, on the western slopes drier semi-evergreen forests are more common.

The moist evergreen forest may have been able to persist on the eastern slopes of the Truong Son despite increasingly dramatic climate fluctuations during the past three million years. Those tropical rainforests may have provided a refuge for forest-dependent species during colder, drier, more distinctly seasonal periods. Such an extra dimension, along which habitat may have expanded or shrunk with time, could help explain why, even in such an Eden of biodiversity as Vietnam, the Truong Son range outshines the rest of the country. (Indeed, in addition to the species we mentioned earlier, the rainforests of the Truong Son harbor about a dozen endemic species of frogs.)

The Anguid Odyssey

Pictured above is a limbless glass lizard of the family Anguidae, genus Ophisaurus. *(These animals may look like snakes, but their ears and movable eyelids are telltale distinguishing features.) Several species of glass lizards are endemic to Southeast Asia, but the story of how they got there (and where they went afterward) is no less interesting than endemism. Originating in North America, the ancestors of limbless glass lizards probably migrated to western Europe between 40 million and 50 million years ago, across a land bridge (not shown in this contemporary map). They then expanded into northern Africa and western Asia. As species radiated throughout eastern Asia, the uplift of the Tibetan Plateau between 10 million and 25 million years ago isolated the new species from populations to the west. At roughly the same time, one eastern lineage returned to North America via the Bering land bridge. The result: Vietnam's three species of glass lizards count different North American species as their distant ancestors and closest relatives.*



Unfortunately, some patterns of endemism are not so easily explained. Vietnam is host to several principal kinds of primates: gibbons (lesser apes), langurs and macaques (which are both monkeys), and lorises (which are prosimians). The ranges of many of those animals are clearly restricted, yet strangely, for many of them, no discernible geographic barrier has been identified.

Several but not all of Vietnam's primate species live only east of the Mekong River, even though there is no apparent reason that they could not raft across. Even more strangely, the ranges of all but two of Vietnam's primates—the lesser slow loris and the bear macaque—are restricted to either the north or the south of the country. A 195-mile-wide transition zone, between 14 and 17 degrees north latitude, serves as a barrier between north and south, but no climatic or geographic reasons have been identified for the existence of this barrier.

Ecologists, confronted with such a checkerboard distribution, have speculated that competition for food or other resources might limit the expansion of one species into another one's range. Although that explanation sounds plausible, it is undermined by the observation

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The golden Vietnamese cypress (Xanthocyparis vietnamensis), *a conifer that inhabits the northern reaches of Vietnam, was first described by scientists in 2001. Mature trees bear both needles (left) and scales (right)—a highly unusual condition for a mature tree. (It is much more common for a conifer to have one kind of leaf when young and the other kind when mature.) The "discovery" was no surprise, of course, to the region's indigenous people; they have long sought out the tree's fragrant wood, leaving the species' survival in serious question.*

that species such as the Assamese macaque and the pigtailed macaque, whose ranges do not overlap in Vietnam, live side by side in Laos and China. Interspecific competition cannot be the only answer.

Other investigators have speculated that glaciation during the Pleistocene Epoch—accompanied by colder temperatures, depressed rainfall, and increased seasonality—might have forced primates into ecological refuges. Species that ended up in the northern areas were presumably better able to manage the cooler weather year-round than were the species that favored the south.

How well do the available data support that hypothesis? The answer is not yet clear. A combination of competition among species for available resources and climatic factors were probably at work, but more study needs to be done before biologists have a solid picture of primate evolution in Vietnam. Biodiversity, it seems, is not merely a result of geographical and climatic obstacles and effects. The irony is that, although geographic ranges are better known for primates than for any other group of organisms in the region, those ranges are perhaps the ones biologists are least able to explain.

In seeking to understand the origins of Vietnam's biodiversity, biologists have to be wary of snap judgments. Particularly for species identified only in the past decade, it is virtually impossible to de-

Where on Earth Is the *Khting Vor*?

Species are often described from remains; such work is the obvious domain of paleontology. But sometimes zoologists hoping to find extant organisms begin by doing the same thing. In 1994 a new ox-like species was described solely on the basis of horns that had been sold as hunting trophies at markets in south-central Vietnam and eastern Cambodia in the early twentieth century. The animal was given the scientific name *Pseudonovibos spiralis,* and it was expected to be similar to other wild cattle found in the same area, including the gaur and the kouprey, or gray ox. Supposedly it inhabited the deciduous and semi-deciduous forests of southern Indochina. Its horns, shaped like a lyre, were ringed with knobs and twisted at the tips: a combination unique among mammals.

The horns, it was thought, might represent the remains of an elusive animal known in the Khmer language of Cambodia as the *khting vor,* a name describing the shape of the horns (from *khting,* meaning gaur, and *vor,* a liana, or creeping vine). In the traditional folklore of the region, the *khting vor* is a snake-eating wild ox. Its horns are held to protect people and their homes against snakes, and are also ground into a powder for treating venomous bites.

DNA was recovered from the horns, but considerable doubt arose from its analysis. Confusingly, it suggested the animal belonged to not one but three quite different subcategories within the family Bovidae: the goats and sheep; the oxen, bison, and buffaloes; and the common domesticated cattle.

Not surprisingly, then, a debate erupted about whether or not the *khting vor* ever existed. Were the horns in fact creations of local craftsmen, prized for their value as ritual objects or in traditional medicine? Further molecular work has shown that the specimens are actually from common cattle, and sophisticated examination of the horns themselves indicates that their unique ringing patterns and torsion were created by carving, heating, and twisting. Given the limited number of horns collected to date (between sixty and seventy), the problems of contamination associated with the recovery of "ancient" DNA, and the extremely limited data on its possible geographical habitats, the question of the *khting vor*'s legitimacy has become extremely difficult to resolve in its favor.

Still, a recent camera-trapping survey of Cambodia, in which cameras activated by tripwires were left in forests, could have finally removed such uncharitable skepticism. Unfortunately, though, no pictures of the animal were obtained. Either the *khting vor* is expert at avoiding zoological paparazzi, or, as with the unicorn before it, its only proper place is in the pages of Jorge Luis Borges's *Book of Imaginary Beings.*

—M.M.H.

termine whether their ranges are restricted by long-term geological or climatic factors, or simply because of habitat loss or degradation. Some species may be "bastard endemics"—occupying only a subset of a formerly larger geographic range—simply because they have retreated, say, to mountaintop islands in a sea of cultivated or seriously degraded land.

Acknowledging the ability of environmental degradation to create endemism brings a practical urgency to the theoretical study of the factors that create endemic species. In short, the study of endemism is not just a pursuit for evolutionary biologists; it is an issue for conservationists and environmentalists to consider as well.

Vietnam has a relatively long history of seeking to redress environmental degradation. As far back as 1962, Ho Chi Minh, the revolutionary general and president of North Vietnam from 1945 until 1969, established the country's first protected area, Cuc Phuong National Park [*see "This Land," by Nguyen Thi Dao, page 70*]. By 1990 more than ninety reserves, covering some 4 percent of the country (or about 3.2 million acres), had been placed under government protection. The Vietnamese government still has plans to roughly double that protected area, but in the region's second most populous nation, the demands of economic development must compete for land with efforts to conserve biodiversity.

In that context, the study of endemism can help governments and others set priorities about what to protect. Certainly it makes sense to determine those priorities, as conservationists have done in the past, on the basis of which species are endemic. After all, if a local population of a widespread species were to go extinct, at least there would still be other populations in the world, but endemic species have much more restricted ranges. The loss of a single population, or a couple of populations of such species, could easily lead to the species' extinction.

The trick, then, is to identify areas of endemism preemptively, without waiting for some remarkable discovery to send everyone scrambling to save a rare and obviously threatened organism. By applying the study of endemism, rooted in the slow passage of deep time, to the problem of conservation—which strives to match the double-time pace of economic development—we might be able to protect areas before they've been thoroughly explored, perhaps leaving some of Vietnam's diversity for the future to discover. □

The gray-shanked douc langur (P. n. cinereus) *was first described by biologists in 1997. It shares the Truong Son with red- and black-shanked douc langur subspecies, which live to its north and south, respectively. This animal, however, was found not in the forest but for sale in a market, and it currently lives in a center for rescued primates. Only a handful of these animals have been seen in the wild. Considerable debate exists as to whether these subspecies ought to be lumped into one species or split into three. For now, the lumpers hold the upper hand.*

Rubbing of a ca cuong *water bug, from an urn in Mieu Temple, Hue, Vietnam*

On the Scent

The trail of a giant water bug leads from Arizona to Vietnam.

By Robert L. Smith

Many years ago, as a graduate student drawn to behavioral ecology and aquatic insects, I encountered my first water bug in the mountain streams of southern Arizona. The species was *Abedus herberti,* a member of one subfamily of giant water bugs, the Belostomatinae. This bug has a remarkable behavior: the male often carries the eggs of its progeny on its back. That same behavior, rarely seen in other groups of insects, has been observed or inferred in more than a hundred species belonging to five genera of the same water bug subfamily. At the time, however, no one had adequately explained it. That's when I knew these bugs were the ones for me.

In my subsequent investigations I learned that the male acquires the eggs while mating repeatedly—sometimes more than a hundred times—with the female. His possessiveness ensures that his sperm alone are responsible for fertilizing all of the eggs she lays on his back. The male then carries the eggs until they hatch, keeping them wet and making sure they can breathe [*see "Daddy Water Bugs," February 1980*].

Sometimes while studying my bugs in mountain streams, I came across another species of water bug, *Lethocerus medius.* That one belongs to another subfamily of giant water bugs, the Lethocerinae, which don't carry eggs on their backs. Instead, the female attaches large clutches of eggs in the open air, to vegetation and other material that emerges above the water's surface. I kept my eye out for her deposits but never saw any, nor did I find any immature bugs. The reason was that these bugs usually live in the still waters of ponds and lakes, not in streams. Arnold Menke, a specialist in water bug systematics, then at the Smithsonian Institution in Washington, D.C., suggested I look for them in the desert, in so-called cattle tanks.

Cattle tanks are natural depressions in the ground. They are usually bone dry in May and June, when surface temperatures can exceed 140 degrees, but they rapidly fill with runoff during the southern Arizona "monsoons"—thunderstorms that arrive soon after the human-made fireworks of the Fourth of July. The ponds begin to teem with algae and other life that has lain dor-

mant, and, summoned by the rains, some insect species in the mountain streams fly to the desert below to gorge on the bounty.

Among the opportunistic migrants is *L. medius,* the largest giant water bug in Arizona. Adults can measure nearly three inches long, and they come equipped with piercing, sucking mouthparts and clawed raptorial front legs. They are big enough to ambush tadpoles too chunky for any other insect predators. The female water bugs use most of their nutrient bounty to produce eggs, whereas the males expend energy on grabbing and defending home bases on the emergent vegetation, from which they court females ready to lay eggs.

In the mid-1980s, in the company of my friend Eric Larsen, then a graduate student working on other water bugs known as back swimmers (he now teaches at the University of Chicago), I began studying the reproductive behavior of *L. medius.* We noted early on that the bugs laid their eggs on sticklike objects extending two feet or more above the water. Mesquite branches, steel and wooden fence posts, and partly submerged cocklebur plants were all popular.

In the second year of work I tried an experiment. I stripped several ponds of their potential egg-laying sites and substituted new ones, sticking several dozen flat wooden stakes into the mud. After several weeks I was pleased to find that eggs had been laid on a number of my stakes. After another week I captured bugs in nets as they were resting underwater on the stakes. Talk about instant gratification! Every stake with eggs also harbored a bug, and every bug was a male! Moreover, stakes without eggs rarely harbored a bug of either sex.

I learned that male bugs not only hang out on the objects that bear their eggs but also brood the eggs by bringing them water. That finding was confirmed independently by Noritaka Ichikawa, a biologist at the Himeji City Aquarium in Japan, working with *L. deyrollei,* a Japanese water bug species. His laboratory studies show that underwater, a brooding bug both imbibes water and saturates its body. The wet insect then quickly crawls up to the eggs and positions himself head down over them, dripping and regurgitating water into the clutch. Ichikawa and I have proved that the eggs of the species we study desiccate and die if left unattended in open air, and that they drown within hours if submerged.

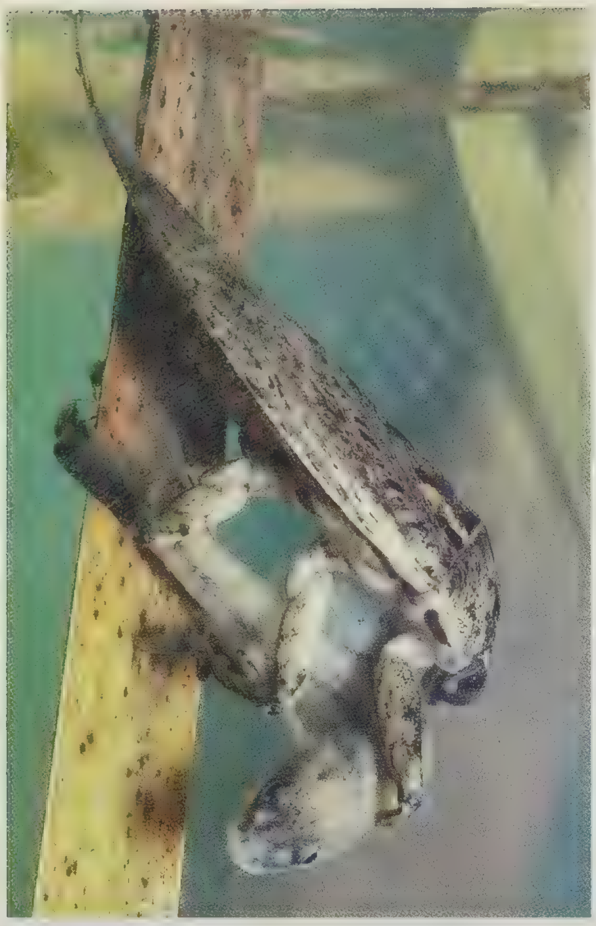
Early in my field research I witnessed my first mating pair of *L. medius.* While the female laid eggs at the lower edge of the clutch, the male demonstrated his commitment by irrigating the eggs from above. But the male also acted just like the males among my "back brooders," regularly interrupting both egg laying and watering to insist on another bout of sex. When the female finally finished laying all her eggs, she swam off, while the male remained behind for about a week, tending the eggs until they hatched.

By lucky accident I discovered that the males were also valiant at defense. One day I tapped several times on the top of an egg-bearing stake with my pocketknife, to seat the stake more firmly in the mud. The resident bug, which had been resting head-down below the water's surface, rushed up to the eggs, covered them with his body, spread his raptorial front legs, and extended his beak. I was so startled that I dropped my knife into the water.

In the minute it took me to retrieve my knife, a possible explanation for such a formidable display occurred to me. Birds might threaten eggs that were suspended above the water (though I had never seen that happen). A charging giant water bug could be a good deterrent, and such behavior would be favored by natural selection. I tested how other bugs reacted to a "pecking bird simulation" and discovered that the bugs' responses were consistent with my hypothesis.

A female L. medius *lays her eggs, while the male above her keeps them moistened with water.*

During several years of observing I was amazed by other feats of the brooding males. If a person (or perhaps a cow) abruptly approached a male positioned on his eggs, the bug would usually jump into the water and swim several yards away. The first few times that happened, I despaired that the dad would ever find his eggs again—but every bug always did, and quickly, even at night. Indeed, male bugs could find the right stake in the midst of a forest of stakes, even if I added extras nearby just to sow confusion. Sometimes, too, a female laid eggs on a dead cocklebur plant. I watched in awe as, even in the dark, the



Among the largest of the giant water bugs, L. medius *dines regularly on small vertebrates such as fish fry and tadpoles.*

male repeatedly ascended the maze of branches, nearly flawlessly making the correct choices at as many as five branching points. How did he do it?

I began to focus on an anatomical feature that had been recognized in *L. indicus,* an Asian water bug species. *L. indicus* possesses a gland with an outlet on the underside of its thorax. Asian biologists have taken a special interest in the gland, because its fragrant exudate is a highly valued flavoring among gourmet chefs, particularly in Vietnam but also in other regions of Southeast Asia and southern China [*see "Bug Juice," opposite page*]. Curiously, the gland occurs in both males and females, but the gland in the male is reported to be as much as twenty-five times larger than the one in the female.

In fact, that organ, called the metathoracic scent gland, is a basic feature of Heteroptera, the insect order to which giant water bugs belong. The organ commonly releases a noxious chemical used in defense (in the stink bug, for instance) or a pheromone used in courtship. Mysteriously, though, the gland is absent in back-brooding giant water bugs such as *A. herberti*. Moreover, though it is present in emergent-brooders such as *L. medius,* biologists had not determined what function it or its products might fulfill for the bug.

A male L. medius *returning from a dip has to navigate to the top of a maze of branches to return to his eggs.*

With the help of William S. Bowers and Philip Evans, chemical ecologists in the department of entomology at the University of Arizona in Tucson, I analyzed the contents of glands from *L. medius* as well as from another North American species, *L. americanus.* Both species contained the same chemical—*trans*-hex-2-enyl acetate—that occurs in *L. indicus,* and both sexes produced it, though the males carried more than ten times as much as the females did. In fact, it now seems that all two dozen species in the genus *Lethocerus* produce the same chemical.

Could the gland be used for defense? Not likely. In handling hundreds of the bugs, I have never had one discharge its scent gland on me (though distressed bugs regularly evacuated the stinky contents of their guts). Besides, the gland product is not noxious or foul smelling; on the contrary, it is very pleasant. Might the gland manufacture sexual pheromones? That, too, is a non-starter. Such attractants are usually produced by only one sex, and typically they are complex chemical blends that differ sharply, even among closely related species. The water bug product is basically made up of one fairly simple compound.

Instead, I think, in emergent-brooding water bugs the gland functions to lay down a chemical trail that can be followed during egg laying and egg brooding. The opening for the gland's secretion is directly between the hind legs, perfect for marking vegetation. If I am right, the gland enables male bugs to find their eggs both day and night. And this explanation accounts for the absence of the gland among back-brooders, whose behavior is thought to have evolved later than that of emergent brooders: they simply don't need it.

Why do both sexes possess the gland when only the males brood? While laying her eggs, the mother water bug periodically returns to the water to refresh herself. Furthermore, she can be knocked off the egg-laying site by her mate's insistent attempts to copulate. The gland may be useful to her in finding her way back to her eggs for the few hours it takes her to finish laying them. But the males apparently need larger glands; they have to find the eggs many times each day for a week or more, not just for a few hours. □

Bug Juice

By Le Anh Tu Packard

My earliest memories of the *ca cuong* water bug can't be separated from the pleasures of eating. My grandmother, who lived with us in Bangkok, would prepare her traditional Vietnamese dish of noodles in a glorious chicken broth topped with thin slivers of omelet, steamed chicken breast, and a smooth-textured paté. It was served with *nuoc mam,* a fish sauce mixed with lemon juice, minced ginger, garlic, and just one drop of the essence extracted from the ca cuong's scent glands. That one drop suffused the dish with an indescribable fragrance, enough for the entire family.

Even at the age of five I knew that the ca cuong was a wonderful, precious creature. In times of war and social turmoil, vials of its aromatic essence were literally a liquid asset, more valuable (and more portable) than gold. My mother told of families that escaped from Laos to Thailand in 1946, driven out by the terror of French bombs. Vials of the sublime essence they brought with them provided the capital they needed to start a new life.

Even after coming to America in 1960, I never stopped yearning for the ca cuong. Miniature vials contributed by visiting relatives were gratefully received and sparingly used. Then, in the late 1980s, an uncle who traveled frequently to Vietnam told me that my beloved ca cuong was hardly to be seen anymore. I was shocked, and resolved to learn more about the fate of this gastronomic delight.

I invited a dear friend who lives in Paris to share his memories of the ca cuong. Noting that their season came in late spring and early summer, he said his images were of bugs caught, cooked whole, and then mashed in a bowl with some nuoc mam fish sauce. The family would gather round, dipping boiled cabbage leaves in the shared bowl. For him, the ca cuong evoked not so much physical or olfactory sensations as the promise of changing seasons. He also recalled an earthy proverb: *Ca cuong chet den dit con cay* (the ca cuong, dead, on reaching the anus remains intense). It is a variant of the adage that no one can change the basic nature of things. That the ca cuong is widely believed to be an aphrodisiac adds further ambiguity to the proverb.

Other friends have offered depictions of the bug—rubbings from a temple in Hue, Vietnam's former imperial capital [*see illustration below and on page 60*]—and recounted stories about the ca cuong in ancient times.

David Marr, a historian at the Australian National University in Canberra, forwarded me a 1928 article on the region's edible insects that includes the story, perhaps apocryphal, of how the bug got its name. Legend has it that Trieu Da (207–137 B.C.), a Chinese general who became ruler of central Vietnam, sent the Chinese emperor a tribute of precious objects, including a number of the insects. The emperor then wrote to ask the insect's name. To inflate the bug's value, Da called it a cinnamon-tree weevil. But the emperor sent back an artfully worded, reproachful reply, that no one in that region would call it by that name, and Trieu Da ought not assume that his betters would be so easily fooled. As a result, the insect came to be called ca cuong, a mangling of the phrase *Da cuong,* meaning "Da embarrassed."

On my first trip back to Vietnam, in 1990, I asked about procuring ca cuong essence. One of my indulgent aunts, who lived in the old quarter of Hanoi, scoured the city, but alas, no luck! The market seemed to have been cornered by people who planned to leave the country.

On my second trip, in 1992, I met Vu Quang Manh, a zoologist and an authority on the ca cuong. (He is currently an associate professor at Hanoi National Pedagogic University and head of the Vietnam Soil Ecology Society.) He told me that the bug, which inhabits ponds and waterlogged fields, subsists mainly on a diet of small fish, tadpoles, large aquatic insects, and snails. According to Manh, even the carcasses of some large waterfowl show signs of the insect's deadly bite.

In the 1980s ca cuong could still be seen flying around Hanoi's Ba Dinh Square, attracted by the lampposts and by the spotlights illuminating the mausoleum of Ho Chi Minh. They were also common near Ho Tay (West Lake). Now they are gone from both places, driven away by chemical fertilizers and pesticides. Manh reports more recent sightings of the bugs in Van Long Wetland Nature Reserve in Ninh Binh Province, south of Hanoi, a pesticide-free riverine wetland.

That this fabulous creature may disappear from Vietnam would be a tragedy for our culture and cuisine—the rough equivalent of abolishing truffles from French cuisine. Fortunately, Manh is leading a project to create a hospitable habitat for the water bug—one free of chemical fertilizers and pesticides. An effort to save the ca cuong is an important component of a wider effort to promote sustainable organic agriculture and to protect Vietnam's environment.

Cultivating the ca cuong and exporting its essence could help poor farmers increase their income and generate hard currency revenues for the nation. Even non-Vietnamese epicures, on tasting the flavor of the ca cuong, may fall under its spell. And why not? Whoever thought, after all, that Westerners would develop such a passion for raw fish? □

The Golden Number

Nature seems to have a sense of proportion.

By Mario Livio

Olivia Parker, *Equinox*, 1992

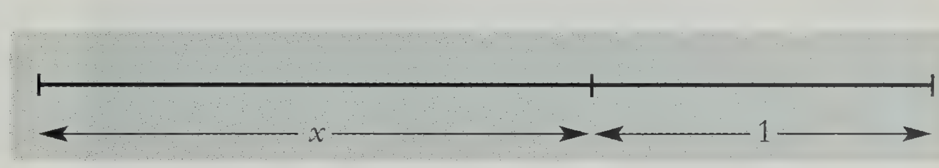
What do:

- the arrangements of sunflower seeds;
- the branching of leaves on a stem;
- the flight path of a diving falcon;
- the breeding of rabbits;
- the spiral shapes of nautilus shells and other mollusks;
- the shapes of spiral galaxies; and
- the way black holes change from one "phase" to another

all have in common? What shared thread connects the petal arrangement in a red rose with the art of Salvador Dalí and the architecture of Frank Lloyd Wright? The answer is, all these phenomena share a close association with a single, extraordinary number. No wonder the number in question has earned the name "golden ratio."

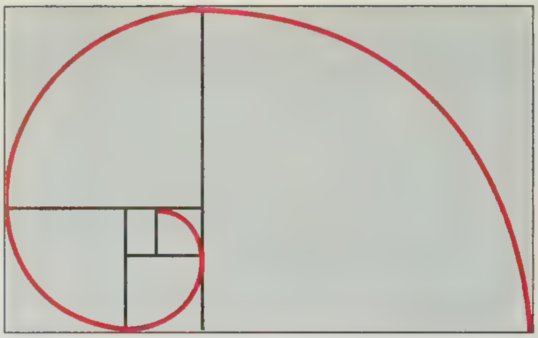
The golden ratio—aka "golden section," "golden number," and even "divine proportion"—is hardly, by itself, a novel concept. The systematizer of Greek geometry, Euclid, who taught in Alexandria around 300 B.C., defined the number in *Elements,* his famous work on geometry and number theory. But Euclid's definition was entirely geometric and betrayed not the slightest acquaintance with the role of the golden ratio in the natural world. In fact, it was nothing more than a modestly amusing way for geometers to divide a line into two unequal parts. Little did Euclid know that his innocent-looking division would preoccupy mathematicians, physicists, botanists, psychologists, and artists for the next few millennia.

Euclid's number (the name "golden ratio" was applied centuries later) emerges from geometry in the following way: Take any line segment and divide it into two parts, in such a way that the longer part of the line segment is in the same proportion to the shorter part as the entire line segment is to the longer part. The ratio in question is the golden ratio [*see diagram below*]. (You don't need to follow the mathematics to understand the rest of this article, but for readers who are interested, here's how to figure out the value of Euclid's number: Suppose the length of the shorter part is 1 and the length of the longer part is x. That makes the length of the original line segment equal to $x + 1$. According to Euclid's definition, then, the value of the golden ratio is $x/1$, the ratio of the longer part to the shorter part. But that ratio must also be equal to $(x + 1)/x$, or the ratio of the original line to the longer part. The solution for x is then a straightforward, albeit technical, matter of high school algebra.)



Turn the crank, and the number that solves the equation for x is equal to the never-ending, never-repeating number 1.6180339887 . . . , commonly denoted by the Greek letter phi, or ϕ. Phi is not to be confused with the Greek letter pi, or π, which stands for a more familiar never-ending, nonrepeating number also present throughout Euclid's work. Pi, whose decimal value is 3.1415926535 . . . , is simply the ratio of the circumference of a circle to its diameter. But pi also makes guest appearances in the most diverse parts of natural science. In that respect phi is like pi: its original definition can be understood by virtually anyone, but it reappears in a remarkable variety of arcane and mysterious guises.

Also like pi, the number phi is an irrational number, one that cannot be expressed as a ratio of two whole numbers, such as 3/1, 3/2, 5/7, or 23/39. In fact, phi is mathematically the "most irrational" number, in the sense that, if you try to approximate it as what is known as a continued fraction (one in which fractions are added in the denominator ad infinitum), you find that the approximation converges on it more slowly than continued-fraction approximations do for any other irrational number.

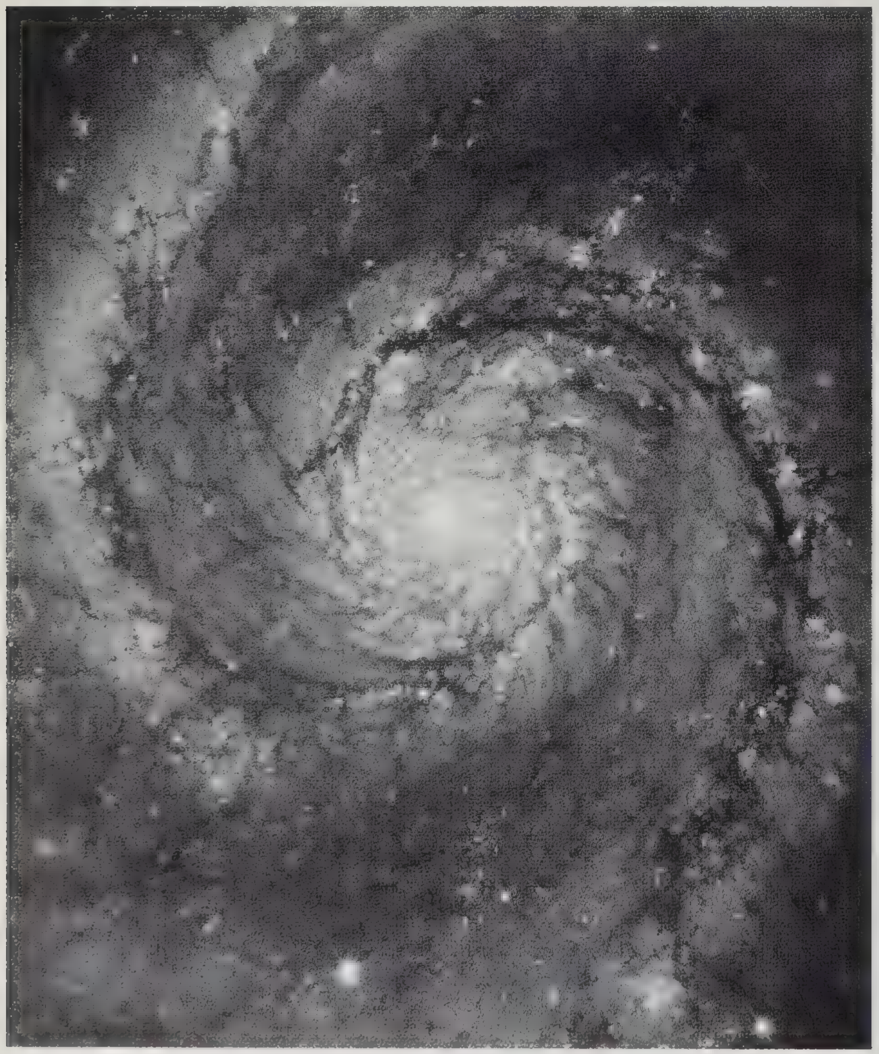


In a golden rectangle the ratio of the longer side to the shorter is equal to phi. A square removed from one end leaves a smaller golden rectangle, and that process can be repeated indefinitely. The smooth spiral that passes through the successively smaller squares is called a logarithmic spiral, whose properties give it special prominence in nature.

The number phi would have remained in the relative obscurity of pure mathematics were it not for its propensity to pop up where least expected. Take, for instance, the head of a sunflower. The florets form various clockwise and counterclockwise spiral patterns, intertwined and crisscrossing but otherwise unmistakable to the eye. Each floret arises in the center of the sunflower and gets pushed outward by its successors; the spiral patterning is an outcome of the way the florets are most easily and efficiently packed as they grow. The number of clockwise spirals and the number of counterclockwise spirals vary, depending on the size of the sunflower. Usually you find 55 twisting one way and 34 the other, but you may find 89 and 55, or 144 and 89. Even 233 and 144 has been reported. Amazingly, if you calculate these as ratios (55/34, 89/55, 144/89, 233/144), you find that they get closer and closer to the value of the golden ratio phi!

The patterning of sunflowers is closely related to one of the discoveries made in 1837 by two French brothers, Auguste and Louis Bravais. Auguste, a crystallographer, and Louis, a botanist, observed that as new leaves are put forth from the tip of many growing plants, each new leaf advances by an angle of roughly 137.5 degrees from the preceding leaf, around the circumference of the stem. That angle is what you get if you divide the number of degrees in a complete circle, 360, by the number phi, and then subtract the result from 360.

But why should the leaves of a plant arrange themselves in a pattern that is based on a number derived from the division of a line? If the angle between the leaves is, say, 90 degrees (which is equal to 360/4), or any other simple fraction of 360 degrees, the leaves will align one above the other on the stem, leaving large spaces unfilled. (In the case of 90 degrees, they will make four lines along the stem.) Such an arrangement would probably be undesirable for the plant, because overlapping leaves would shield one another from the light they need. By arranging themselves according to an angle determined by phi, the leaves can fill the spaces in the most efficient way possible, with the least amount of overlap.



Whirlpool Galaxy, in the constellation Canes Venatici

Botany is hardly the only context in which the golden ratio appears. Take the so-called golden rectangle, in which the ratio of the length to the width is equal to phi. If you snip off a square from the rectangle, the rectangle that remains is also a golden rectangle. You can continue this process of snipping off squares ad infinitum, generating smaller and smaller golden rectangles. No other rectangle gives rise to the same shape as you snip off successive squares. If you then connect the successive points where the whirling squares cut the sides of the rectangles, you get a curve known as a logarithmic spiral [*see illustration at top of page*].

The name follows from an observation by the seventeenth-century Swiss mathematician Jakob Bernoulli. Bernoulli noted that the logarithm of the distance from the spiral's center at any point along it is proportional to the angle by which you advance. To express the same thing another way, if you follow the spiral through a series of full, 360-degree turns, the distances measured along the rays

emanating from the center, or "pole," of the spiral to a point on the curve form a geometric series. In other words, each distance is a constant multiple of the preceding one.

Bernoulli recognized that the logarithmic spiral does not alter its shape as its size increases, a property known as self-similarity. For that reason, Bernoulli noted, the spiral "may be used as a symbol, either of fortitude and constancy in adversity, or of the human body, which after all its changes, even after death, will be restored to its exact and perfect self." He asked to have the spiral engraved on his tombstone—but, sadly, ignorance prevailed, and the tombstone artist carved only the simple coil (the shape formed by, say, a role of paper towels) known as the Archimedean spiral.

Another intriguing property of the logarithmic spiral is that it is equiangular: if you draw a straight line from the pole to any point on the spiral curve, the line always cuts the curve at precisely the same angle. Falcons bank on this property when attacking their prey. Vance A. Tucker, a biologist at Duke University in Durham, North Carolina, studied falcons for many years and discovered that they usually follow a slightly curved trajectory to their victims, rather than plummeting in a straight line. Tucker eventually realized that the falcons' trajectory could be a consequence of keeping the fovea of one or the other eye, the most acute part of their vision, locked onto their target. To make use of the fovea during a straight downward plunge, the falcons would have to cock their heads some forty degrees to one side or the other. But Tucker showed in wind-tunnel experiments that cocking the head would slow the falcons down considerably. By keeping their heads straight while keeping their target in view from the most advantageous angle, the falcons naturally follow the curve of a (highly drawn-out) logarithmic spiral.

Nature just loves logarithmic spirals. You can find them in phenomena ranging from the shell of the chambered nautilus to hurricanes and spiral galaxies. Sometimes, as in the case of the nautilus, they are a natural outcome of a pattern of additive growth. And it is through that pattern that the golden ratio is intimately related to the Fibonacci sequence, a celebrated series of numbers discovered by the early thirteenth-century Italian mathematician Leonardo of Pisa, known as Fibonacci.

Bill Varie, *Rose in Bloom,* 1998

In his book *Liber abaci* ("Book of the Abacus"), published in 1202, Fibonacci posed the following fanciful problem about the breeding of rabbits:

> A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair, which from the second month on becomes productive?

The solution to the problem is fairly simple. Start with one pair of baby rabbits. After a month you still have only the one pair of rabbits, now nearing maturity. In the third month, however, you have two pairs of rabbits (the original pair, plus their first two babies). Come back in another month and you have three pairs, because the first pair has generated another set of babies. In the fifth month you have five pairs (because the first pair of babies has become old enough to reproduce). And so on.

You end up with the sequence of numbers 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, and so on, in which each term (from the third on) is equal to the sum of the two preceding terms. The sequence was named the Fibonacci sequence by the nine-

teenth-century French mathematician Edouard Lucas. For the sake of historical accuracy, one should note that this sequence of numbers actually appeared even earlier than Fibonacci, in a rule for the construction of meter in a category of Sanskrit poems known as *mātrāvrittas*. Indian poets wrote about the rule in detail before Fibonacci was born, but Western mathematicians were unaware of their contributions until the appearance of a 1985 article by Parmanand Singh, a mathematician then at Raj Narain College in Hajipur, India.

You may have noticed that some of the numbers in the Fibonacci series have already been mentioned: they are the same as the numbers of clockwise and counterclockwise spirals appearing in sunflowers. And recall that the ratios of the numbers of spirals were good approximations of phi. It turns out that if you calculate the ratios of successive Fibonacci numbers [*approximated to the sixth decimal place in the table at right*], the ratios oscillate about phi but also converge on it as you go farther out along the sequence.

1/1 =	1.000000
2/1 =	2.000000
3/2 =	1.500000
5/3 =	1.666667
8/5 =	1.600000
13/8 =	1.625000
21/13 =	1.615385
34/21 =	1.619048
55/34 =	1.617647
89/55 =	1.618182
144/89 =	1.617978
233/144 =	1.618056
377/233 =	1.618026
610/377 =	1.618037
987/610 =	1.618033

Thus Fibonacci numbers are a kind of golden ratio in disguise, and they, too, pop up in the most unexpected places. One is in the microtubules of an animal cell, which are hollow cylindrical tubes of a protein polymer. Together they make up the cytoskeleton, a structure that gives shape to the cell and also appears to act as a kind of cell "nervous system." Each mammalian microtubule is typically made up of thirteen columns, arranged in five right-handed and eight left-handed structures (5, 8, and 13 are all Fibonacci numbers). Furthermore, occasionally one finds double microtubules with an outer envelope made up—you guessed it—of 21 columns, the next Fibonacci number. The precise reason that the Fibonacci numbers show up in microtubules is not clear, but some investigators have argued that microtubules structured this way are more efficient than other possible structures are as "information processors." Because these sets of numbers are so small, however, the apparent connection with the Fibonacci series may be coincidental.

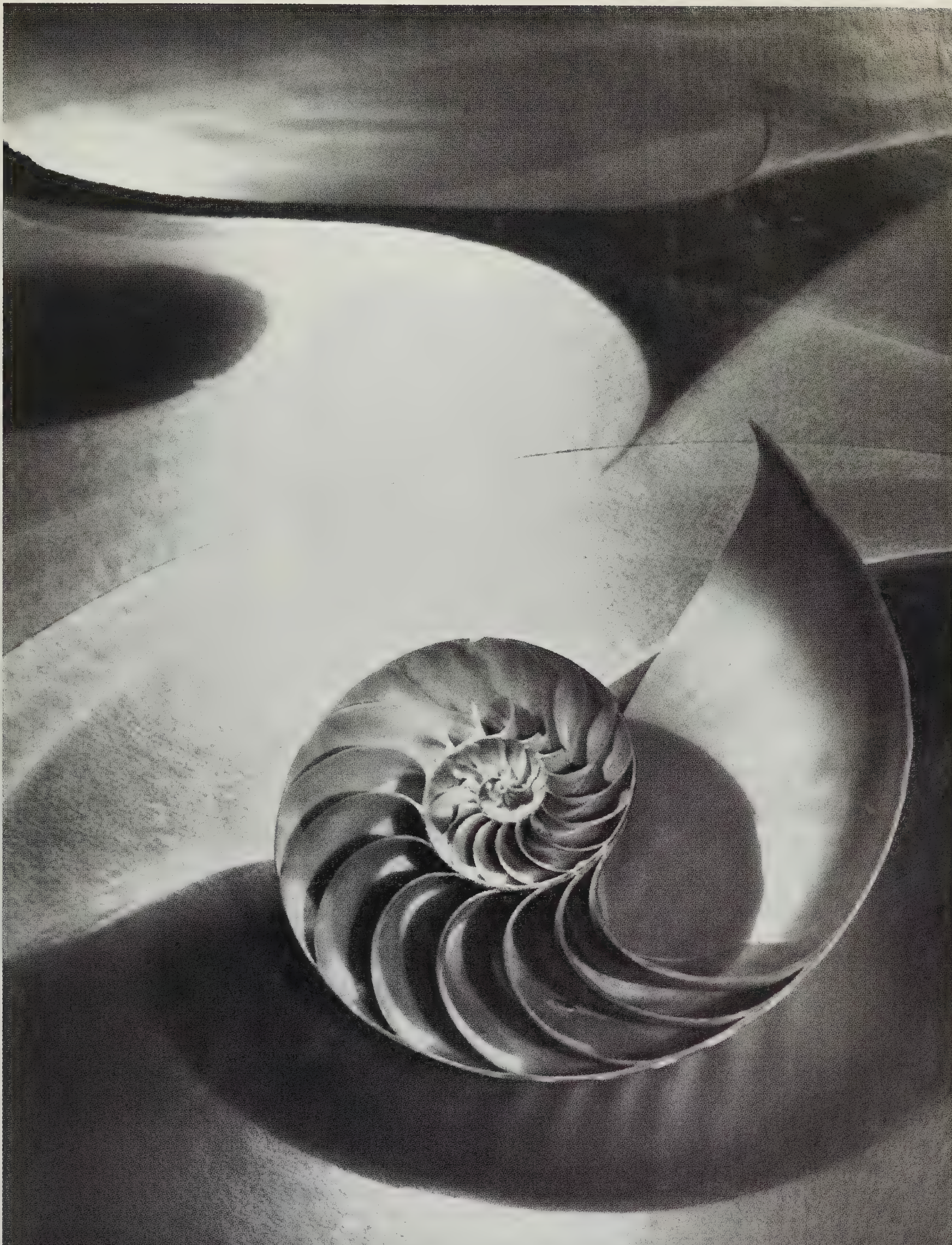
Turning from the microscopic to nature on a large scale, one finds that the spiral arms of many disk-shaped galaxies are often close to logarithmic spirals [*see photograph on page 66*]. The spiral arms stand out because that is where many stars are being born, and younger stars, on average, are brighter than older ones. But how do such spiral arms retain their shape over long periods of time? The reason this question is an astrophysical puzzler is that a galaxy does not rotate about its center like a disk of solid material, in which all parts simultaneously make a complete circuit. Instead, the closer to the center the stars or other matter lie, the faster they rotate. A spiral arm made up of some fixed group of bright stars should quickly get "wound up"—but that would imply that spiral galaxies were much rarer than they are observed to be.

The explanation is that the spirals are not structures of connected material streaming out from the center of a galaxy, as they might appear. Instead, they are the result of waves of gas compression sweeping through the disk. Where gas is compressed, the birth of new stars is triggered. Because matter is not uniformly distributed throughout the galaxy, the waves sustain a spiral effect as a kind of interference pattern.

The golden ratio makes an unexpected appearance even in the thermodynamics of certain black holes. Black holes can be either nonrotating (in physicists' terms, they have no angular momentum) or spinning. Spinning black holes (called Kerr black holes, after the New Zealander physicist Roy Kerr) can exist in two states, one in which they heat up when they lose energy and one in which they cool down. They also can undergo a phase transition from one state to the other. The transition can take place only when the black hole reaches a state in which the square of its mass is precisely equal to phi times the square of its angular momentum (in the appropriate units). This seemingly magical appearance of phi stems from another unique mathematical property of the golden ratio: its square can be obtained simply by adding 1 to phi (you can check that statement with a pocket calculator).

In this and countless other ways, the golden ratio triggers the feeling of amazement that Einstein regarded as essential for all intellectual endeavors. In Einstein's words:

> The fairest thing we can experience is the mysterious. It is the fundamental emotion which stands at the cradle of true art and science. He who knows it not and can no longer wonder, no longer feel amazement, is as good as dead, a snuffed-out candle. □



Carlotta Corpron, *Chambered Nautilus in Space Composition,* c. 1950

My Life as a Forest Creature

Growing up with the Cuc Phuong National Park

By Nguyen Thi Dao

Forest vegetation hugs the rugged karst terrain.

I was born in a hammock on a forest path in Cuc Phuong National Park. (The health center to which my mother was being carried was just a little too far away.) The path is still used, though it no longer leads back to our home. As a little girl, I was lucky enough to have the forest as a playground, but my family was relocated out of the park in the late 1990s. Unfortunately my favorite litchi trees were not relocated with us.

Declared a protected area by Ho Chi Minh in 1962, Cuc Phuong became Vietnam's first national park in 1966. It was spared the effects of the war, unlike much of the nation's environment. Covering roughly ninety square miles, it encompasses forested limestone karst mountains and one main, central valley. Sometimes we children were caught in restricted areas by the forest rangers, but not often. I remember one ranger gently telling me not to leave my machete—we all carried rusty knives back then!—stuck in a tree trunk while I played. The machete, he said, could kill the tree.

My friends and I took little-used routes to the outer edges of the valley to graze and mind our cows and water buffalo—the job of most rural kids. Mainly, though, our cows grazed themselves, and we explored the forest and the streams. Adventure was always around the corner. Once, while collecting wild honey from a hive of the large forest bees, I was caught by the angry swarm. I will never forget the panic. Luckily, one of the village elders picked me up, held me tight, and spat chewed rosebud juice at each of the stings, gently dabbing it on. The pain instantly subsided.

On another occasion I was walking through the forest, looking for my cow, when I suddenly felt I was being watched from above. I looked up and saw a green snake as thick as my big toe. I was scared stiff and ran as fast as I could through the dense forest, paying no heed to the scratching thornbushes. Snakes are common in Cuc Phuong; some, such as the banded krait, are deadly poisonous.

My friends from the local Muong ethnic group told me that if you didn't disturb the snakes and the bees, they wouldn't go out of their way to hurt you. Relocated from their traditional villages in the center of the park, the Muong now occupy shanties in the parched, stony foothills. From their dusty doorways they can hear the thrumming forest and sense the karst mountains towering above, even when the peaks are shrouded in clouds.

The legendary May Bac ("silver cloud") Peak was the place I thought most of conquering, because it is the highest mountain in the park, about 2,100 feet. Once you are up there, you are enclosed in a cloud of forest mist. Sometimes the cloud creeps into the bottommost corners of the lowest valley.

The forest is never still. Insects, particularly the humming cicadas, are its pulse. Tree frogs that never come down to the ground break into a chorus on some unseen and unfelt cue; land crabs the size of small dogs clatter through the undergrowth.

Butterflies light up the gloom, congregating in sunny spots and above pools. At least 280 species, including birdwings, live in the park. They often land in muddy areas, and when you come near them, they take off and circle around you. In spring and summer I used to swim in a colorful butterfly sea. It felt like being in a fairy world.

It rains a lot in summer. I once got

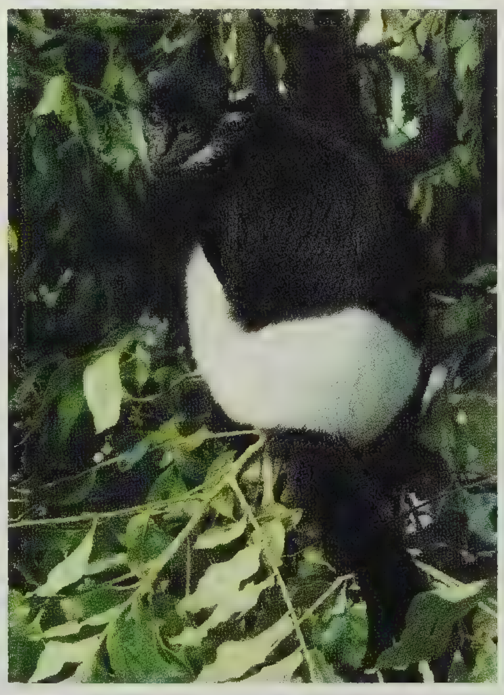
lost with my friends in a downpour. We thought it would be a good idea to follow a stream out of the forest, because we knew that streams sometimes intersected our usual paths. How disappointed we were when the stream we were following suddenly disappeared underground! (Now I realize that Cuc Phuong has a natural underground drainage system that absorbs all the rainfall.) Luckily, we found our way out after five hours of struggle, soaked and mosquito bitten. A lot of leeches helped themselves to our blood.

There are many caves in the park's limestone terrain. We used to play hide-and-seek in them; they were pleasantly warm in winter and cool in summer. The must-visit exemplar is Nguoi Xua Cave (prehistoric man cave), where human remains as old as 12,000 years have been discovered.

The best season to visit Cuc Phuong is from the beginning of December, when the heavy rains are over, through April. It is often dry and pleasant then. But as children, my friends and I found summer to be the best season for collecting wild fruits, many of which are similar to their cultivated counterparts. We had to compete with the squirrels and bats.

Cuc Phuong is home to an estimated 2,000 plant species; just last year my brother, a park botanist, discovered a new orchid *(Vietorchid aurea).* The park is also renowned for its big trees. The most famous one is a thousand-year-old *Terminalia myriocarpa.* It takes seventeen people to encircle it, stretching their arms around its trunk.

About 450 species of mammals, birds, reptiles, and amphibians—38 percent of the known species in Vietnam—live in the park. Many are endemic, such as Delacour's langur, which we Vietnamese often call the white-shorts langur because of its white bottom. It is a hard animal to spot in the forest, because the vegetation is dense and these monkeys are very smart.



Delacour's langur

Young Owston's palm civets

It is lovely to wake up in the morning in the park; you hear the birds singing and you see them flying overhead. You can also see the silver pheasant along the trails; the males look particularly handsome with their long white tails.

Many nocturnal animals also live in the park, such as Owston's palm civet, which loves to eat the noisy crickets and quiet earthworms. When I was a child in the forest at night, the bats swooping past my ears or the movement of an unseen animal in the dark would make my hair stand on end. Sometimes it still does. But it is always magical on a summer's eve when the fireflies are out; they make the forest look like a Christmas night, with thousands of little lights blinking in giant Christmas trees.

For visitor information, contact:
Cuc Phuong National Park
Nho Quan District
Ninh Binh Province
Vietnam
(84-30) 848-006/-009/-007
Fax: (84-30) 848-008

A SAMPLING OF SPECIES

Mammals Clouded leopard, Asian golden cat, Owston's palm civet, Asiatic black bear, crested gibbon, Delacour's langur, Phayre's langur, lesser slow loris, Chinese pangolin, Cuc Phuong squirrel, giant flying squirrels, and horseshoe bats.

Birds Eurasian tree sparrow, white-rumped munia, scaly-breasted munia, common kingfisher, white-breasted kingfisher, melodious laughing thrush, black-throated laughing thrush, long-tailed shrike, green peafowl, grey peacock pheasant, silver pheasant, great hornbill, Indian pied hornbill, chestnut-necklaced partridge, red-collared woodpecker, and red-vented barbet.

Other animals include snakes, such as cobra, king cobra, and banded krait; geckos, turtles, and frogs; fish (among them the Cuc Phuong catfish) and crabs; and countless insects and spiders.

Trees *Parashorea chinensis, Terminalia myriocarpa, Tetrameles nudiflora, Cinnamonum balansae, Dracontomelum duperreanum,* and Cuc Phuong pear.

Nguyen Thi Dao is a conservationist with the World Wildlife Fund Indochina Programme.

Let's Make a Galaxy

Astronomers have identified a cosmic infant "nearby"—70 million light-years from Earth.

By Charles Liu

Galaxies in the universe are rather like the cells in an animal. Just as cells combine to make an animal's organs and systems, so, too, do galaxies come together to make the superclusters and filaments that define the large-scale structure of the cosmos. Not surprisingly, in much the same way that biologists examine cell development to understand the aging process in animals, astronomers study galaxy formation to decipher the evolution of the cosmos. Hence, the study of the origin of galaxies is one of the most important topics in modern astronomical research.

In this case, though, the biologists have it much easier. Animals reproduce, and so biologists have a steady supply of newborn cellular agglomerations for comparison and scrutiny. But astronomers have only one universe to observe, and it's mighty long in the tooth—13 billion years old, according to the best current estimates (about three times the age of Earth). Worse, according to current thinking, the vast majority of galaxies formed long, long ago. So when we astronomers want to study the earliest moments in galactic "life," we have to approach our work more like paleontologists than like biologists, seeking to understand an ancient world with only fossilized remains as a guide. To glimpse galaxies in their embryonic stages, astronomers have to look far back in time, across distances amounting to billions of light-years. Of course, such great distances pose severe challenges even for the most powerful telescopes. Unfortunately, there is no other choice.

Then again, maybe there is. In the past several years, new evidence has suggested that some galaxies may still be forming. Now, according to astronomers Michael R. Corbin of the Space Telescope Science Institute in Baltimore and William D. Vacca, now at the University of California in Berkeley, a smoking gun may be in view—a nearby galaxy, caught in the act of birth.

What do we astronomers mean by "galaxy"? We usually recognize one when we see one, but ask us for a definition and we have a much tougher time. Here's a reasonable working definition: a galaxy is a vast, contiguous collection of stars, gas, dust, and other matter, totaling at least a few million times the mass of the Sun, all held together by mutual gravitational attraction. At least our own Milky Way fits the definition pretty well—though it's on the hefty side as galaxies go, made up of about 100 billion stars that stretch across 100,000 light-years.

Blue compact dwarf galaxy, POX 186

According to current models, between two and four billion years after the universe began with a (big) bang, clumps of matter had formed in vast numbers. Each clump was larger than a typical cluster of stars, but smaller than a modern-day galaxy. As gravity acted on these subgalactic clumps, pulling them ever closer together, regions of space that were already relatively dense with clumps became even denser, and did so more quickly, than regions where the clumps were initially relatively sparse. Large collections of clumps created deep gravity wells that sucked in smaller groups of clumps, even as those collections coalesced to make single, larger bodies. Today, billions of years later, we observe the resultant hierarchy of cosmic structure: subgalactic clumps that combined to form galaxies, which in turn gathered into groups and clusters, which then collected into filaments and superclusters.

Since all that clumping and clustering started so long ago, cosmologists don't expect, by and large, to find such primordial subgalactic objects in the universe today. Much of the current observational research on galaxy formation therefore focuses on dwarf galaxies, with less than one-hundredth the mass of the Milky Way. Some kinds of dwarfs have many more young stars than do their larger siblings, and offer the possibility of studying present-day galaxy evolution on a manageable scale.

Corbin and Vacca examined a sample of dwarf galaxies chosen for their compact size and the youth of their star populations. One of the dwarfs, called POX 186, caught their eye. (The

nomenclature has nothing to do with skin disease—"POX" is a kind of shorthand for the informal name of the survey that discovered the object in 1981.) With the Hubble Space Telescope, Corbin and Vacca made a high-resolution image of the galaxy—and found a small, apparently newborn minigalaxy just 70 million light-years away and a mere 100 million years old. The shape, size, and age of the dwarf galaxy all seem consistent with the idea that POX 186 is actually made up of two partly coalesced subgalactic clumps, in the act of coming together to make a new galaxy.

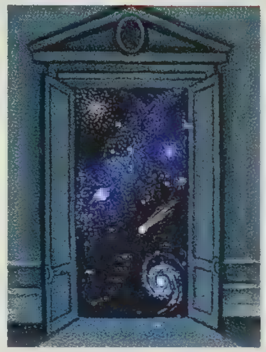
How could such a young galaxy be forming before our eyes? After all, according to conventional wisdom, subgalactic clumps were all swept up long ago into galaxies like our own. The location of POX 186 may provide a critical clue. Nestled between matter-rich filaments and superclusters are "voids" of intergalactic space. Only a sparse smattering of galaxies occurs in these vast, empty volumes of space. POX 186 resides near the edge of such a void, in the direction of the constellation Boötes; Corbin and Vacca found no other galaxies within 15 million light-years of the dwarf. Maybe that's why the two subgalactic clumps survived so long: exiled in the void, they remained undisturbed for more than 10 billion years, never encountering any other clumps—until now.

The discovery that a nearby dwarf galaxy is actually in its infancy is, though fascinating, hardly heretical. In fact, understanding the ancient, distant subgalactic clumps is still essential for unraveling the mysteries of galaxy birth and formation. But POX 186 does open the door to a new line of inquiry, because astronomers now know that it's also worthwhile to look closer to home. More little blobs of matter may be lurking in the voids.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN MARCH

By Joe Rao



Mercury, acting more the lamb than the lion, enters March still lost in the Sun's glare. It reaches superior conjunction—disappearing, from our perspective, behind our star—on March 21. Thereafter, it begins climbing into the western evening twilight. By month's end, equipped with binoculars, you might see the planet just above the western horizon about half an hour after sunset. Mercury gets higher in the sky with each passing day, on its way to its best showing in 2003, which takes place during the first half of April.

Bright **Venus,** unmistakable at magnitude –4, rises at about 4:30 A.M. local time all month long. A telescope shows it in gibbous phase, a small replica of the gibbous Moon. At sunrise in early March it is less than 20 degrees above the horizon, as seen from mid-northern latitudes, and each week it sinks lower in the sky, heading toward superior conjunction. The planet is now fleeing ahead of Earth in our race around the Sun, but its seemingly breakaway speed is mostly the effect of having the inside track; its speed, about 22 miles a second, is only slightly greater than Earth's 18.5. Seen from our moving platform in space, Venus will disappear into the glare of the Sun in July and pass behind the Sun in mid-August.

Mars ascends about four hours before the Sun, crossing the meridian overhead shortly after sunup. The planet moves rapidly eastward through the constellation Sagittarius in March, appearing as a fairly inconspicuous yellowish orange light near the constellation's teapot pattern. The big Martian show, though, comes in late August, when Mars, having shifted into the

evening sky, will be more luminous and closer to the Earth (about 34.6 million miles away) than it has been in many millennia. Perhaps in the year 2287, when the two planets again approach within 34.6 million miles of each other, people will be gazing at Earth from the surface of Mars.

Jupiter is king of the night sky this month. Visible high in the south during the evening hours, the brightest "star" in the sky after Venus invites inspection the moment you set up a telescope. As seen from Earth, Jupiter is in retrograde motion, moving westward through the dim stars of the constellation Cancer. By month's end it lies less than a degree away from the famous Beehive star cluster, which appears in binoculars as a swarm of points. Jupiter's bright disk against this background should make a pretty sight. On March 14 a waxing gibbous Moon passes about 3.5 degrees above and to the left of Jupiter.

Saturn appears high in the constellation Taurus in the south-southwestern sky at dusk. The planet sets shortly after 2:00 A.M. local time on March 1 and about two hours earlier by the end of the month. Even a small telescope reveals Saturn's wonderful rings, tilted almost as far as they ever tilt toward Earth. Saturn will be 90 degrees east of the Sun, or at east quadrature, on March 13. The long shadow the planet casts on its rings is easily seen from Earth, giving the ensemble a greater appearance of depth.

The **Moon** is new at 9:35 P.M. on March 2 and reaches first quarter at 2:15 A.M. on the 11th. It is full at 5:34 A.M. on the 18th. Last quarter comes at 8:51 P.M. on the 24th.

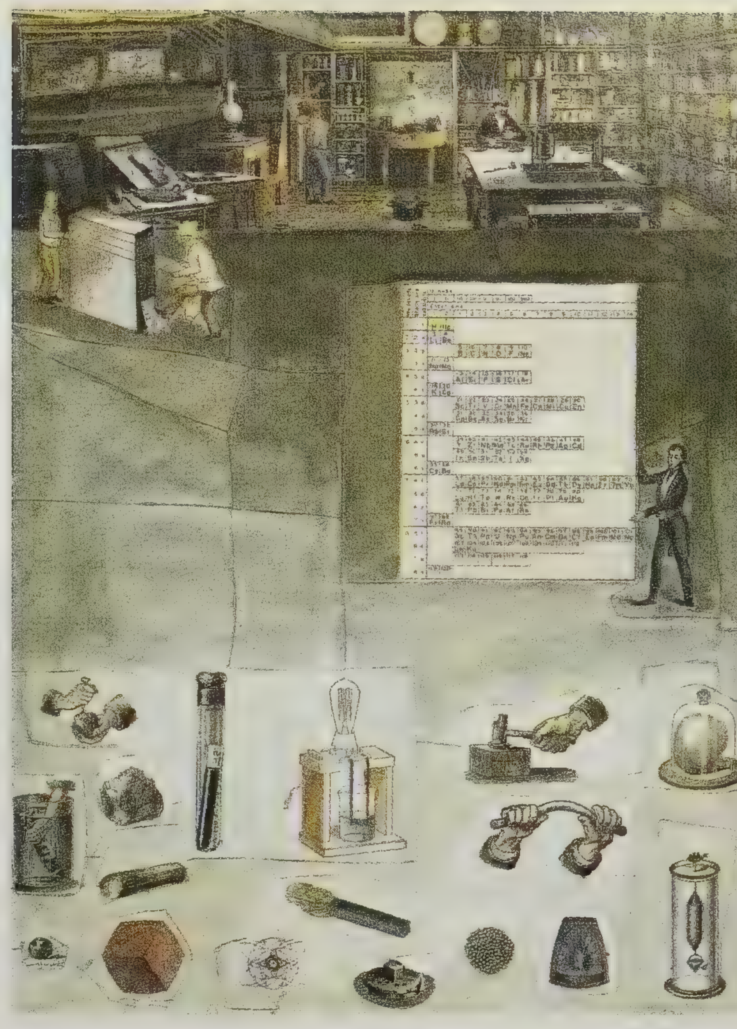
The **vernal equinox** takes place—and spring begins in the Northern Hemisphere, autumn in the Southern—at 8:00 P.M. on March 20.

Unless otherwise noted, all times are given in Eastern Standard Time.

Table Talk

Stories of the stuff that makes up the world

By Hans Christian von Baeyer



Vivian Torrence, *The Periodic Table,* 1991

When I was in college nearly half a century ago, we students were entranced by the inimitable campus bard, Tom Lehrer, singing "The Elements." At a breathtaking pace he rattled them off:

There's antimony, arsenic, aluminum, selenium, /And hydrogen and oxygen and nitrogen and rhenium /And nickel, neodymium, neptunium, germanium, / And iron, americium, ruthenium, uranium, /Europium, zirconium, lutetium, vanadium /And lanthanum and osmium and astatine and radium /And gold, protactinium and indium and gallium [inhale] /And iodine and thorium and thulium and thallium.

The song went on to list a total of 102 elements, but Lehrer, then a math instructor at Harvard, was well enough informed to end on a cautious note: "These are the only ones of which the news has come to Harvard, /And there may be many others but they haven't been discovered." His caveat turned out to be well advised. The most recent element to be discovered, number 118, was promptly undiscovered again.

What a world of drama and mystery is evoked by those wonderful names! The occasional familiar one—life-giving oxygen, much-coveted gold—saves the list from academic obscurity and imbues it with an aura of relevance. At the same time, the strange names cry out for more information. What does that one look like? Is it normally a gas, or a solid, or perhaps even a liquid like mercury? Who discovered it? When? Where? How? What does the name mean? What's it good for? The lore and lure of the elements—the stuff that we and the rest of the universe are made of—cast their spell far beyond the circle of professional chemists.

For answers to the questions conjured up by Lehrer's ditty back in the '50s, I used to turn to my "rubber bible." We all called it that, rather than *The Handbook of Chemistry and Physics,* because it was published by The Chemical Rubber Publishing Company and printed on thin India paper, like a bible. Now in its eighty-third edition (my tattered copy is the thirty-eighth), this fat book has been an indispensable reference for four generations of scientists. Before computers, that's where you looked up stuff like the value of the tangent of 79.7 degrees, the density of sulfur, and all the other grains of information that give physical science its gritty texture.

The Ingredients: A Guided Tour of the Elements
by Philip Ball
Oxford University Press, 2003; $22.00

In the middle of the good book, between a list of electronic configurations and the periodic table, there was an essay titled "The Elements"—like the song. It was an alphabetical list of thumbnail sketches, each no longer than a paragraph, of the properties and histories of the elements, from actinium to zirconium. In 3,000 pages, one brief chapter was the only repository in the great reference for anecdotes about people and stories about places of origin, discoveries, applications, and etymologies. This brief section of my bible relieved the tedium of the surrounding pile of dry data, and provided a reassuring reminder that the entire enterprise is of human origin.

Although an alphabetical listing of the elements is more practical than Lehrer's purely poetic arrangement, it is not much more scientific. The number of ways to shuffle a hundred names is almost unlimited. A historian of science might compile a list

by year of discovery—starting with Aristotle's element of water, which Antoine-Laurent Lavoisier unmasked as a compound in 1783, and ending with the nameless superheavies that seem to be forever embroiled in controversy. An economist might classify the elements by price, an industrialist by usefulness, a geologist by abundance on Earth, an astronomer by their place in the scheme of nucleosynthesis, a physician by necessity for health. By far the most significant list for scientists is Dmitri Mendeleyev's periodic table of 1869—one of the great triumphs of the human intellect.

But what if you want to conduct a guided tour for the public? How would you choose your itinerary? Which of the possible enumerations of nature's building blocks would most suit your stroll? The answer, of course, is "none of the above." The Italian writer Primo Levi's semi-autobiographical book *The Periodic Table* comprises only twenty-one elemental chapter names. "Brilliant Light," the English-American neurologist Oliver Sacks's reminiscences of his chemical boyhood (published in *The New Yorker* and later expanded in his book *Uncle Tungsten*), pushes the envelope of inclusiveness with mentions of forty-five elements. Sacks recalls how he once drove his parents to distraction with an enraptured chemical monologue until they were forced to exclaim: "Enough about thallium!" List mania, even in the scientific realm, is not a universal passion.

Philip Ball, an English science writer and contributing editor for *Nature,* is far too experienced to become boxed in by the lure of comprehensiveness. He explains his approach in the preface: "No piano tutor would start by instructing a young pupil to play every note on the keyboard. Far better to show how just a few keys suffice for constructing a host of simple tunes." Accordingly, his little book is divided into just seven chapters, with the history and explanation of the periodic table taking pride of place in the middle. Leading up to it is a short history of the elements, from Aristotle to the seventeenth-century chemist Robert Boyle, followed by two intimate portraits of individual elements.

The first close-up describes oxygen as "a bridge between the new and the old, between the alchemical roots of Robert Boyle's 'chymistry' and the syntheses of endless wonders in today's chemical plants." The second sketch, of gold, begins with the story of King Midas and his golden touch. Here Ball stumbles. His degrees in physics and chemistry establish his authority in things scientific, but like other scientists he can become careless when recounting myths—as though it didn't matter, since they are fictitious anyway! He conflates various versions of the Midas tale, moves Midas's landlocked kingdom of Phrygia from central Anatolia to the distant shores of the Aegean Sea, and, without comment, injects a gruesome nineteenth-century embellishment in which Midas turns his daughter to gold.

What a world of drama and mystery is evoked by the names of the elements!

The chapter of Ball's book devoted to the convoluted history of the periodic table describes its profound impact on chemistry and physics. For Sacks, who as a boy was enchanted with chemistry, the table was "the most beautiful thing in the world." Its explanation in terms of Niels Bohr's 1913 model of the atom shone like a "brilliant light" of understanding.

Ball's own youthful experiences with the periodic table were less lyrical but more productive. When he was required to write an examination essay on niobium, for instance, his mere knowledge of its position in the periodic table encoded enough chemical information to enable him to fill several pages. The genius of Mendeleyev shines brightly from the pages of Ball's book, underlining the blatant injustice of his being passed over for a Nobel Prize. (He was a leading candidate in 1905 but was edged out by Adolf von Baeyer, my great-grandfather.)

The final three chapters bring the story up to date. Ball describes nuclear accelerators as atom factories for synthesizing short-lived, heavy elements—atom by expensive atom. He explains the isotopes—chemically identical forms of an element, which differ only in atomic weight—with special emphasis on their usefulness in historical, geological, and even astronomical dating. And he ends the tour with a glimpse at the world of applications, starting with ubiquitous iron and concluding with the noble gas argon which, after a century of haughty celibacy, was finally induced to form a compound in the year 2000.

After I finished reading this charming little book, I felt a bit shortchanged: How can a map (the periodic table), two leisurely stops (at oxygen and gold), and four tutorials add up to a "guided tour"? But when I looked for the names of elements in the index, I was astonished to count eighty-four, excluding tabulations. Practically all of them are there! Ball's achievement is the exact opposite of Lehrer's: It teaches by seduction, where the latter startles by exhibitionism. By weaving the elements seamlessly into a coherent narrative, the author has given meaning to the entire system without overwhelming the reader with the profusion of its parts. That's good writing.

Hans Christian von Baeyer is Chancellor Professor of Physics at the College of William and Mary in Williamsburg, Virginia, and the author of Taming the Atom: The Emergence of the Visible Microworld. *His next book, on information, will be published this summer by Weidenfeld & Nicolson.*

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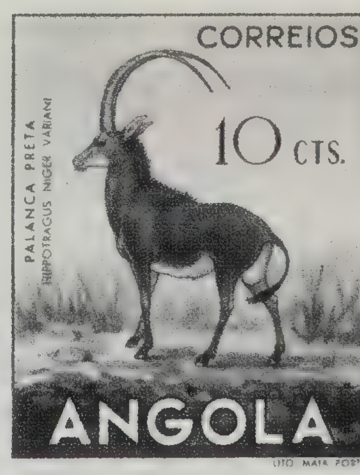
By Laurence A. Marschall

A Certain Curve of Horn: The Hundred-Year Quest for the Giant Sable Antelope of Angola
by John Frederick Walker
Atlantic Monthly Press, 2002
$26.00

Animals can compel our love or admiration. Some amuse us; some annoy us. But only a few can enchant. For some reason—their bearing, their elusiveness, the remoteness of their habitat—such special animals embody an idealized view of nature, becoming the locus of human projections of power, nobility, and sensitivity of near-mythic proportions. The bald eagle, the gray whale, and the snow leopard are three such creatures. And so is the giant sable antelope of Angola, the subject of John Frederick Walker's fascinating account, and a rare and endangered mammal that few people outside its homeland have ever heard of.



Any visitor to a game park in southern Africa can attest to the beauty of the common sable antelope, two races of which *(Hippotragus niger kirkii* and *Hippotragus niger niger)* roam the savannas from South Africa to Zambia. Jet black, with ramrod bearings and large arcs of heavy horn on their equine heads, they are a sight impossible to forget. But the giant sable *(Hippotragus niger variani)*, whose horns are almost a foot longer than those of its common relatives—and whose markings are even more striking—has been seen in the wild by only a few naturalists. In the 1800s travelers heard rumors that such animals lived between the Zambezi River and the western coast of Africa, and an enormous horn, more than five feet long, mysteriously showed up in the University Museum of Natural History in Florence, Italy. But no European had ever seen the antelope in the flesh.

Hunters—and in the early decades of the twentieth century most naturalists were hunters—wanted not only to see the giant sables but to bag them. Following the discovery of a few herds of giant sables in central Angola by a British railway engineer, Frank Varian, just before the First World War, a few heads and hides made it to the trophy rooms and museums of the world, but sightings were sporadic. Until the 1970s, when the behavioral ecologist Richard D. Estes, now head of the International Conservation Union's Antelope Specialist Group, conducted the first (and only) field studies of the giant sable, little was known about its habits, how closely related it was to other species, or even the size of its population.

It didn't help that the homeland of the giant sable was deep in the center of Portuguese West Africa, one of the most repressive and neglected of the European colonies. Before the last decades of the twentieth century, the region was scarcely touched by modernization; Portugal's chief interest—until Angola achieved independence in 1975—seemed to be extracting as much mineral wealth as possible with the labor of an oppressed population, and then shipping it along the one railway (which Varian had helped build) that connected the frontier with the Atlantic coast.

But independence scarcely made things better. The pre-independence freedom fight degenerated into a civil war that tore the country apart for the rest of the century. By some estimates,

more than a million Angolans died and some 12 million land mines were emplaced. In the ensuing chaos even the few naturalists who study the giant sable lost track of them. There was fear that many of the antelopes had been caught in the crossfire: even though Angolans venerate the giant sable as an icon of their nationhood, the warring armies have been known to slaughter other endangered species for the lucrative profits that the animals' pelts, horns, and ivory bring on the black market—or simply for a bite to eat.

Has the giant sable survived? John Frederick Walker, a journalist who caught the enchantment of the animal in his youth, decided to find out for himself. The resulting book, a riveting account of his research and travels, recalls Peter Matthiessen's tale of a similar search for the snow leopard in the frigid Himalaya. But where Matthiessen struggled against inner ghosts, Walker mainly does battle with bureaucratic bungling and Third World corruption, making his book more a chronicle of the politics of conservation than a search for the meaning of life. It would spoil a wonderfully told story to reveal how it all comes out.

Coal: A Human History
by Barbara Freese
Perseus Publishing, 2003; $20.00

The history of coal, of course, spans time on a geologic scale. Yet Barbara Freese, a former assistant attorney general of Minnesota, brings welcome brevity to that history in this readable book about the black stone Emerson called "a portable climate." The thesis of Freese's book, not startling by any means, is that coal is a mainspring of the modern world: love it or hate it, it is here to stay. It generates most of our nation's electric power, and will continue to do so as other fuels become depleted. But the use of coal poses urgent challenges for the quality of life on our planet.

It was in Great Britain that the use of coal first took hold, perhaps because of

its abundance in readily accessible outcrops. As London and other great population centers burgeoned in the fourteenth century, forests began to vanish, and coal became the fuel of choice. Yet as early as the thirteenth century, royal commissions had been set up to deal with pollution from coal burning. Apparently their efforts were to no avail, for in a seventeenth-century book with the apt Latin title *Fumifugium* (from *fumus*, "smoke," and *fugo*, "to chase away"), a minor government official named John Evelyn described atmospheric contamination that blotted out the Sun, resulting in a capital city that resembled "the Suburbs of Hell." Four hundred years of official concern had led only to a worsening of London's smog problem—and that was before the Industrial Revolution!

Coal seller, c. 1830

Even royal worry could not stop the use of coal, it is clear, because its immediate value as a fuel far outweighed the inconvenience of soot-stained sheets and acrid breezes. And if coal had been essential to the emergence of urban England from the Dark Ages, it was even more important as mercantile and agricultural societies in the West began to transform themselves into industrial powers. Freese sketches the impressive role of coal in feeding the forges of England and in transforming the virgin continent of North America into a nation of railways and manufacturing centers.

These examples from the great sweep of history highlight the deep and abiding chasm between the power of coal to create wealth and the enormous costs that unleashing such power exacts from society. Although Freese shares the wonder of the Victorians at the accomplishments of industrialized civilization, she doesn't skimp on describing its dark side. The coal that powers our industries—bringing cheap textiles, central heating, and fresh fruit into our lives—also causes black lung disease, mine disasters, and acid rain. In her penultimate chapter Freese describes a visit to China, which seems to be reprising the Industrial Revolution in fast-forward. There, coal still plays the central role it once played in the West, despite growing competition from nuclear, natural gas, and hydroelectric energy sources. At an accelerating rate—and with a population greater than that of Europe and North America combined—China is making the same mistakes.

But today the stakes are higher, as coal consumption continues to rise. It's not just London, Pittsburgh, or Beijing anymore; the planet as a whole suffers when fossil forests burn. Cities in the eastern United States feel the stinging breath of Midwest power plants. The smoke from Shanghai wafts over Los Angeles. And global atmospheric concentrations of carbon dioxide threaten to alter the climate in ways that, though still uncertain in their details, will undoubtedly be momentous. As this human history of coal makes clear, there are no easy answers. But books as lucid as Freese's make a welcome contribution to the search for a sustainable energy economy.

Measuring America: How an Untamed Wilderness Shaped the United States and Fulfilled the Promise of Democracy
by Andro Linklater
Walker & Company, 2002; $26

In January of 1790, addressing the new U.S. Congress for the first time, George Washington set forth three priorities for the fledgling nation: to defend its sovereignty, to strengthen its economy, and to establish a uniform system of weights and measures. In its modern-day guise of "homeland security," that first imperative continues to preoccupy Washington today, as does the economy. But the integrity of common measuring standards is secure across the land. Grain merchants no longer use larger bushels to buy from the farmer than to sell to the miller, and "a quarter-pounder" weighs the same in Boise as it does in Baltimore. The success of George Washington's program for reforming weights and measures, Andro Linklater argues, was essential not just to the eventual emergence of a consumer economy, but to the development of the national character of the United States.

What the founding fathers had in mind was not merely to establish fair and uniform measures, but also to create a framework for the general commerce of the nation. The central feature of this vision was to measure, to classify, to rationalize the land itself. Armed with standard English measuring chains (the origin of the twenty-two-yard-long unit), compasses, and transits (surveyor's instruments with mounted telescopes), the surveyors laid out a rectilinear grid from coast to coast, following imaginary beelines across rugged brush, treacherous mudflats, and precipitous mountainsides.

The payoff for the surveyors' monumental effort was that it became easy to sell homesteads and mineral rights, to establish towns, to construct railroads and canals. America's reputation as a land where hard labor is repaid by

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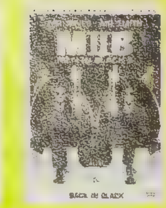

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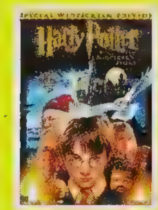

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success—a reputation that drew immigrants from far and near—has its roots in the uniform survey maps and section markers of these survey parties.

For all the good intentions, though, the measurement of America was neither as systematic nor as rational as its originators might have wished. Linklater cites a good many cases in which judgment was skewed by the inertia of local custom or the expedience of politics. One of his most entertaining and enlightening anecdotes is the story of how the U. S. might well have chosen the metric system from the start, given its clear superiority over pounds, gills, acres, and chains.

Thomas Jefferson led the fight for metric measurement, and was the most influential champion of a system based on decimal multiples of the length of a pendulum that swung through its arc once a second. Not only would the system be easy to manipulate; it also relied on a standard kept not by the government but, in effect, by the immutable laws of physics. By the time Washington addressed the Congress, it was conventional wisdom

Metric series—length, c. 1880

that some such scientifically based decimal system ought to guide the new nation, and decimalization of length and weight seemed only a vote away.

But the French Revolution changed all that. In the 1790s the French officially adopted a metric system based on the length of a quadrant of the Earth's meridian. The segment of longitude they chose to measure ran just to the east of Paris—decimal to be sure, but linked, unfortunately, with the geography of continental Europe. Congress, unable to properly distinguish Jefferson's system from the one tarred by the French Revolution, began to drag its feet, wondering why it should get rid of the familiar inches and yards in favor of a system based on a line through a foreign city.

By the time the system came up for a vote, surveyors had already begun to divide and sell vast tracts of land in the Ohio Valley, using the old English measures. The explosion of land sales settled the issue de facto: Too much time and money had already been invested in the old system. It was too late to change. The U.S. did adopt a decimal coinage. But the great land surveys, the building of the railroads, and the growth of American industrial society itself all took place under a uniform but cumbersome system of units first elaborated in the sixteenth century.

Laurence A. Marschall, author of The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

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Les Grands Sites

By Robert Anderson

The French Ministry of Culture and Communication has created a tour de force with its "Great Archaeological Sites" (www.culture.fr/culture/arcnat/en/grsites.htm), a collection of nine elegantly designed Web pages, conveniently translated into English, that merit your attention as a browser even if you aren't a devotee of French history.

I was first drawn to the collection by a page offering a virtual tour of Chauvet-Pont-d'Arc Cave in southern France. Soon I found myself hopping around France and across the centuries, traveling back to prehistoric times, Roman Gaul, and the Middle Ages. The tour of Chauvet gave me a good feel for the layout of the cave's subterranean galleries, with their magnificent examples of figures and forms created 31,000 years ago: spotted panthers, engraved horses, a procession of red rhinoceroses, and the ubiquitous hand-print "signatures" of the Paleolithic artists. In the case of Chauvet, virtual viewing is not just a surrogate for visiting in person; it is, lamentably, as close as most people will ever come to seeing those treasures. Like the better known Lascaux Cave (another featured site in the virtual collection), it is sealed to the public because the acidic combination of carbon dioxide and water vapor exhaled by throngs of tourists would condense on the cool walls and corrode the artwork.

The collection also includes Arago Cave, near France's border with Spain, where the 450,000-year-old Tautavel Man was discovered; a look at the Gallic populations of Provence; and an investigation of a trio of medieval villages northwest of Grenoble settled by "farmer-knights." Finally, from the country that gave the world Jacques Cousteau, the French ministry offers a site dedicated to underwater archaeology. You can spend fascinating hours, all warm and dry, exploring a host of discoveries off the Atlantic and Mediterranean coasts of France, submarine sites in Egypt, and shipwrecks around the world.

Robert Anderson is a freelance science writer living in Los Angeles.

EXPLORER GUIDE

Unique Collaboration Culminates in Exhibition

When the exhibition *Vietnam: Journeys of Body, Mind & Spirit* opens at the American Museum of Natural History in New York on March 15, 2003, it will be the product of an unprecedented collaboration between the AMNH and the Vietnam Museum of Ethnology in Hanoi. The institutions share a common mission of studying, preserving, and interpreting culture, and their collaboration provides an ideal opportunity to reveal the richness of Vietnamese culture to an American audience.

Vietnam and the United States share a difficult and complex history. Perhaps because the two countries did not resume full diplomatic recognition until 1995, Vietnam is still largely misunderstood by Americans whose knowledge often is limited to memories of the war. Vietnam is, in fact, an incredibly diverse country, with more than 50 ethnic groups. Showcasing Vietnamese culture, with its melding and juxtaposition of the traditional and the contemporary, the exhibition provides American audiences an unprecedented opportunity to experience life in Vietnam in the 21st century. Such an exhibition would not have been possible without the partnership of two museums on opposite sides of the world.

The AMNH has a significant history of scientific and scholarly work in Vietnam, beginning with zoological expeditions in the early 20th century. More recently, in 1997, the AMNH's Center for Biodiversity and Conservation (CBC) initiated a biodiversity project in Vietnam in conjunction with the Missouri Botanical Garden, the Institute of Ecology and Biological Resources in Hanoi, and the Vietnam National University, Hanoi. As the project developed, it became clear that the study of an ecosystem was incomplete without information about the people who lived and worked there.

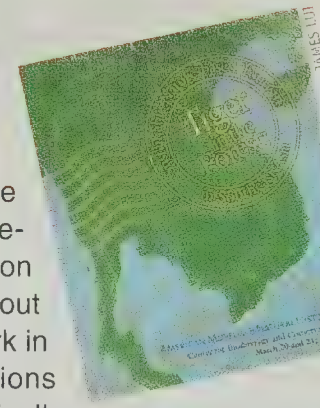
Vietnam Museum of Ethnology intern Hoang Thi To Quyen during her training in the objects conservation lab at the American Museum of Natural History

The AMNH and the VME had begun a relationship in the early 1990s when Nguyen Van Huy, Director of the VME, and Laurel Kendall, Curator of Asian Ethnographic Collections at the AMNH, traveled to each other's institutions to discuss future projects. In 1998, the VME became the local sponsor of the ethnographic component of the CBC's Vietnam project. In 1999, plans for a major collaborative exhibition on Vietnamese culture took shape, with Drs. Kendall and Huy as co-curators.

As the relationship has developed, each institution has benefited from the experience and expertise of the other. The VME has provided many objects in the exhibition and the scholarly expertise to interpret them. The AMNH has lent its conservation and curatorial expertise and years of experience in developing exhibitions. AMNH staff members have held training workshops in Hanoi on textile and object conservation, ethnographic field methods, collection cataloging, and curation, and, in turn, have learned from VME staff about Vietnam and its material culture. As plans for the exhibition have stepped up, five professionals from the VME have served residencies at the AMNH conserving objects and helping AMNH curators interpret and describe the artifacts to be exhibited. Three more have traveled to the AMNH to help prepare for the exhibition's March 15 opening.

Just as the exhibition focuses on the notion of journeys, the collaboration itself can be seen as a journey—of two countries with a complex and difficult past moving toward a future of understanding and friendship. According to Dr. Kendall, "An encounter with Vietnam in the 21st century is an important step toward healing."

Center for Biodiversity and Conservation's Spring Symposium Addresses Sustainable Tourism



Much of the world's biodiversity is located in developing tropical countries, areas that have become increasingly popular as tourist destinations. While the traveling public's growing interest in visiting these unique places can bring with it much-needed revenue and jobs, as well as increased incentive to conserve natural areas, many scientists are concerned that tourism-related activities will result in serious consequences for already threatened ecosystems.

Increased pollution; overuse of natural resources; the introduction of invasive species; disruption of migration, feeding, and breeding patterns; habitat transformation; and even harassment of animals are among the possible—and potentially irreversible—ramifications of nature-based tourism. There is also urgent concern about maintaining and protecting a region's cultural integrity, which can be enormously affected by the influx of visitors and increased industry.

Tourism is now the world's largest industry, and nature-based and cultural travel is widely considered its fastest growing segment. While such travel now accounts for an estimated $100–200 billion per year worldwide, there is still no universally agreed-upon definition of the word "ecotourism," nor are there standard industry or policy guidelines to minimize its impact on the environment or cultures.

On March 20 and 21, 2003, the Museum's Center for Biodiversity and Conservation (CBC) will address this complex topic during its eighth annual symposium, *Tiger in the Forest: Sustainable Nature-Based Tourism in Southeast Asia.* A key aim of the conference is to develop recommended guidelines for decision makers, tour operators, conservation practitioners, and consumers.

The decision to focus the 2003 symposium on nature-based tourism and its impact on biodiversity conservation grew out of the CBC's long-standing work in Southeast Asia and discussions with colleagues there, specifically those in Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, and Vietnam. In discussing the various factors that affect biodiversity in this region, which harbors a significant proportion of the world's rare and endemic plants and animals, tourism emerged as an important issue.

Tiger in the Forest will provide an important forum for information exchange and partnership-building among biologists, tourism-industry professionals, conservation practitioners, governmental decision makers, and community stakeholders. The conference sessions will focus on the needs of unique and fragile ecosystems; the economic and conservation potential of nature-based tourism; case studies of well designed, properly monitored, and sustainable tourism sites; and sharing of cautionary tales of lessons learned. In addition, the symposium will examine what responsible travelers can do—no matter what the destination—to minimize their impact on natural areas and biodiversity.

The symposium is organized by the CBC in collaboration with the Wildlife Conservation Society and World Wildlife Fund.

In 1993, in response to increased threats to biodiversity, the Museum created the CBC to focus its scientific and educational resources on conservation policy and action.

TIGER IN THE FOREST: SUSTAINABLE NATURE-BASED TOURISM IN SOUTHEAST ASIA

Thursday and Friday, March 20 and 21
9:00 a.m.–6:00 p.m.

Advance registration is recommended. Please visit research.amnh.org/biodiversity or call 212-769-5200.

C. CHESEK/AMNH

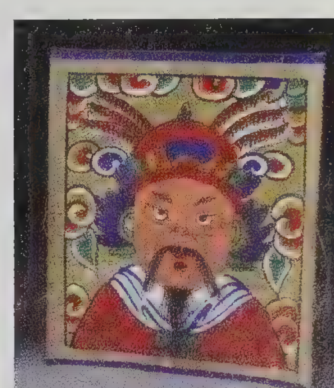
These paintings are worn as masks during Yao initiation rituals in Vietnam.

Vietnam: Journeys of Body, Mind & Spirit

March 15, 2003–January 4, 2004
Gallery 77, first floor

Explore daily life in the early 21st century among Vietnam's more than 50 ethnic groups. The objects on display range from the traditional to the contemporary, and often merge the two, reflecting the dynamic process that has created modern Vietnamese culture.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. Additional generous funding provided by the Ford Foundation for the collaboration between the AMNH and the VME. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.



MUSEUM EVENTS

EXHIBITIONS

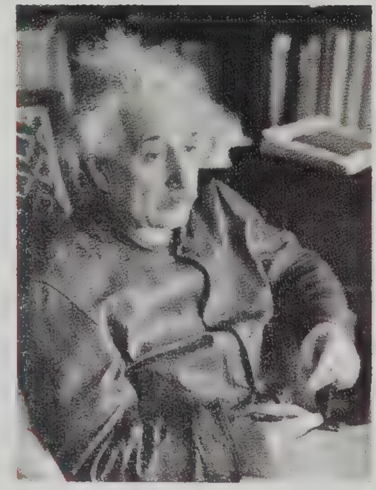
Biodiversity of Vietnam
Opens March 20
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals and the Museum's Center for Biodiversity and Conservation's ongoing research there.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

The First Europeans: Treasures from the Hills of Atapuerca
Through April 13
Gallery 3, third floor
The First Europeans reveals the mysteries of ancient humans in western Europe through exquisitely preserved hominid and animal fossils found in northern Spain.

Co-organized by the American Museum of Natural History and Junta de Castilla y León.

Einstein
Through August 10, 2003
Gallery 4, fourth floor


LOTTE JACOBI COLLECTION/UNIVERSITY OF NEW HAMPSHIRE

This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 26, 2003
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.*

CONFERENCE

Vietnam in the 21st Century: Journeys on the Ground and in the Imagination
Saturday and Sunday, 3/22 and 3/23
10:00 a.m.–5:00 p.m.
This conference on recent fieldwork in Vietnam highlights contemporary marriage, tourism and local identity, environmental issues, religious traditions, and more. Please call 212-769-5891.

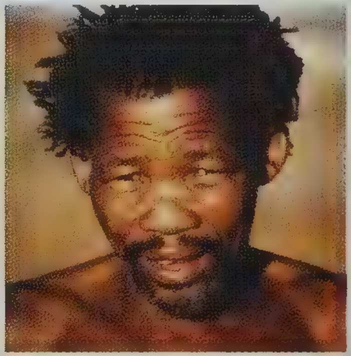
FILM SCREENING

Tay Puppet Story: Tham Roc Village
Vietnam Museum of Ethnology and Richard Connors. 2000. 30 min.
Sunday, 3/23, 12:30 p.m.
In this story of cultural revival, the last surviving members of a venerable puppet troupe lead young apprentices in mounting the first public performance in nearly 50 years. Post-screening discussion.

LECTURES

Women as Society Builders
Saturday, 3/8, 10:30 a.m.–1:00 p.m.
Celebrate International Women's Day with an address by Mae Jemison, the first African American female astronaut, followed by film screenings and tours of Museum exhibits.

Beneath the Myth of the Kalahari Bushman
Thursday, 3/13, 7:00 p.m.
Travel writer Rupert Isaacson discusses his book *The Healing Land: The Bushmen and the Kalahari,* followed by a book signing.


RUPERT ISAACSON

Dawid Kruiper, traditional leader of the Xhomani bushmen

The Empty Ocean
Tuesday, 3/18, 7:00 p.m.
Richard Ellis addresses the fate of the ocean's wildlife in his latest book, *The Empty Ocean.*

Journeys: A Dialogue
Tuesday, 3/25, 7:00 p.m.
The co-curators of *Vietnam* will discuss how staff of two museums with distinct traditions of museum practice worked together on the exhibition's implementation.

WORKSHOP

Animal Drawing
Eight Thursdays, 3/6–5/1
An intensive drawing course among the Museum's famed dioramas.

FAMILY PROGRAMS

Andrew Lost
Saturday, 3/15, 2:00 p.m.
Meet author J. C. Greenberg.

R. MICKENS/AMNH

Identification Day
Saturday, 3/29, 1:00–4:30 p.m.
Bring your basement curios and garage-sale finds of natural and cultural objects to this perennial favorite event, and Museum scientists will try to identify them. Please call 212-769-5176.

Puppets on Parade
Saturday, 3/29, 1:00–4:30 p.m.
Explore the diverse art of puppetry as it illustrates traditional and contemporary stories. Please call 212-769-5315.

CHILDREN'S ASTRONOMY PROGRAMS

I Want to Be an Astronaut
Saturday, 3/8, 12:00 noon–1:30 p.m., or 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Star Myths: An Introduction to Mythology
Sunday, 3/16, 1:00–2:30 p.m.
(Ages 7–9)

Fly Me to the Moon
Saturday, 3/29, 12:00 noon–1:30 p.m., or 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Space Explorers
Myths and Constellations of the Spring Sky
Tuesday, 3/11, 4:30–5:45 p.m.
(Ages 12 and up)

HAYDEN PLANETARIUM PROGRAMS

The Life and Death of Planet Earth
Monday, 3/3, 7:30 p.m.
Peter Ward discusses his latest book, coauthored with Don Brownlee.

Cosmos 1: Reaching for the Stars
Monday, 3/24, 7:30 p.m.
Learn how "light pressure" has the power to send a solar sail out among the stars. With Louis Friedman.

Celestial Highlights
Tuesday, 3/25, 6:30–7:30 p.m.
This monthly tour of the heavens offers a view of the constantly changing night sky.

SPACE SHOWS

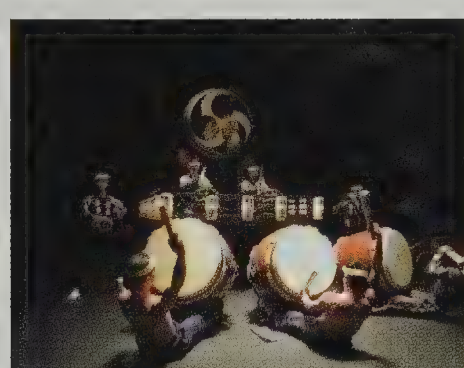
The Search for Life: Are We Alone?
Narrated by Harrison Ford
Every half hour, Sunday–Thursday and Saturday, 10:30 a.m.–4:30 p.m.; Friday, 10:30 a.m.–7:30 p.m.

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

LARGE-FORMAT FILMS

In the Samuel J. and Ethel LeFrak IMAX® Theater

Pulse: a STOMP Odyssey



Scene from *Pulse: a STOMP Odyssey*

Take a rhythmic voyage of discovery around the world of percussion and movement.

Kilimanjaro: To the Roof of Africa
Follow a team of hikers up Africa's highest mountain.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

COME ON IN, THE WATER'S FINE!

The Museum Shop features an ocean of new items to celebrate the May re-opening of the Milstein Hall of Ocean Life. A new line of products celebrating the iconic Blue Whale, plush sea creatures, and a variety of distinctive gifts are available now. Stop in or log onto www.amnh.org.

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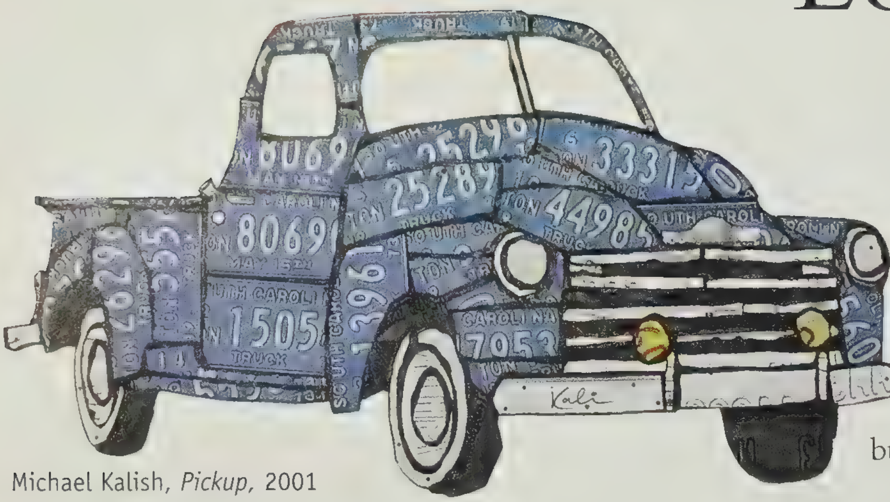
- Free subscription to *Natural History* magazine and to *Rotunda,* our newsletter
- Invitations to Members-only events and previews

For further information 212-769-5606 or visit www.amnh.org.

Lost and Found

By Beth A. Middleton



Michael Kalish, *Pickup*, 2001

My father always knew just which direction he wanted to go and how he wanted to get there. Of course he did have a secret: he and his truck never left the secure confines of the dairy country south of Lodi, Wisconsin. He drove the back roads of Dane County in a big Ford F-150 pickup on his rounds, delivering tractor oil to the farmers and carrying pesticides back to our own place—the same pesticides that probably caused his kidney cancer. I marveled at how he never got lost.

I have fond memories of wandering our farm, bringing my father his lunch during the spring field work. On his infrequent breaks he taught me—as his mother had taught him—the names of the plants and animals that tenaciously clung to the wild nooks and crevices of our land. My farm background turned out to be excellent training for my adult occupation as a wetlands ecologist and environmentalist.

After my father died, I rescued his truck from our dirt-floor garage. Its back bumper, which had taken the brunt of many an unloaded oil barrel, drooped as forlornly as the tail of a dog that's lost its master. The cab still smelled vaguely of farm animals and cigar smoke. I fixed it up and made it my own.

The pickup had been the perfect vehicle for my father, but it raised eyebrows and drew surprised comments from my colleagues in Carbondale when I self-consciously parked it next to their Toyotas and Hondas in the faculty parking lot of Southern Illinois University. "It was my dad's," I told them, as though that would explain everything.

One day I drove the truck out of comfortable, rural southern Illinois and into the city of Saint Louis. I was driving alone, with no one sitting beside me to read the map, and memorized the route before entering the city. But on my way back, I missed a turnoff on the interstate and suddenly found myself in heavy traffic on a highway unknown to my mental map. I tried to find a place to pull off and study my Rand McNally, but all the exits led to abandoned buildings and blighted industrial complexes.

Few urbanites understand the panic the city brings on in country bumpkins. If we get lost, we risk being blinded by fright. We have no survival skills for the city. John Muir, America's most famous country bumpkin, grew up on a farm not far from my parents' place. So Muir and I were both products of the same rural landscape. When the obstacle of Louisville stood in Muir's way during his famous thousand-mile walk, he navigated the city with his compass and talked to no one.

Now here I was on an unknown highway, surely headed into the city's most treacherous section, and all I had to guide me out of danger were my farmer's instincts—the legacy of generations of people living close to nature. My father had taught me to love the land, hate the politics. Surely there was something in that philosophy to guide me out of this heart of darkness called Saint Louis.

Cars and trucks hurtled by at amazing speeds. "Go east, drive to the river," my ancestors shouted—just when my brain was millimeters away from stone-cold shutdown and my heart was pounding like a half-killed rabbit going into shock. And so I steered my dad's truck along a course that followed no map except the faint natural marks of the land. I drove east, away from the sun. The road began to slope toward the river. My heart pounded less; my head cleared. The blighted city gave way to cranes and riverside loading equipment and then, there were the Mississippi and the Gateway Arch to Illinois. I drove across some bridge and soon found myself in the farm country east of Saint Louis. The wheels of my dad's truck hummed beneath me. I was safely on my way back home.

Beth A. Middleton is now a research ecologist at the U.S. Geological Survey's National Wetlands Research Center in Lafayette, Louisiana.

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The world has become a smaller place in the past few decades. Transactions take place across the world in an instant. Having a timepiece that can not only keep perfectly accurate time, but keep track of the time zones can be really helpful and convenient. Now there is a watch that can scientifically give you the right time in all zones within the 2,000-mile radio signal range.

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Does anyone really know what time it is?

Well, the U.S. Government wants to, so they created the National Institute of Standards and Technology, a component of the U.S. Department of Commerce. The Time and Frequency Division, located in Boulder, Colorado, maintains the F-1 Fountain Atomic Clock, the nation's standard of time. This clock neither gains nor loses a second in 20 million years. This watch is the next best thing to having your own atomic clock, because it automatically displays the precise accurate time. It sets itself to the F-1 Fountain Atomic Clock using a working battery, it adjusts itself for daylight saving time and leap years, and it features a variety of practical and convenient features to fit your lifestyle.

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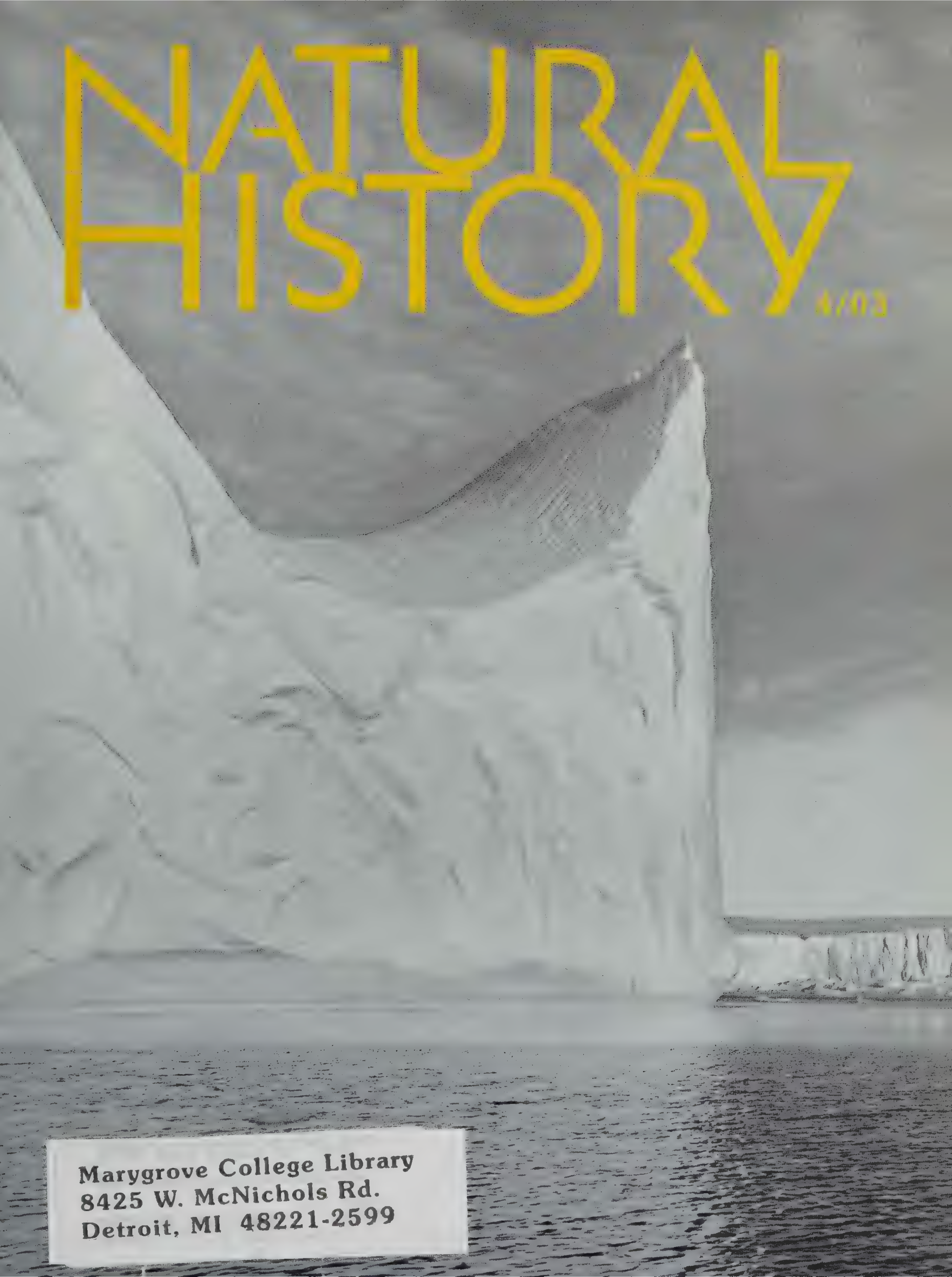
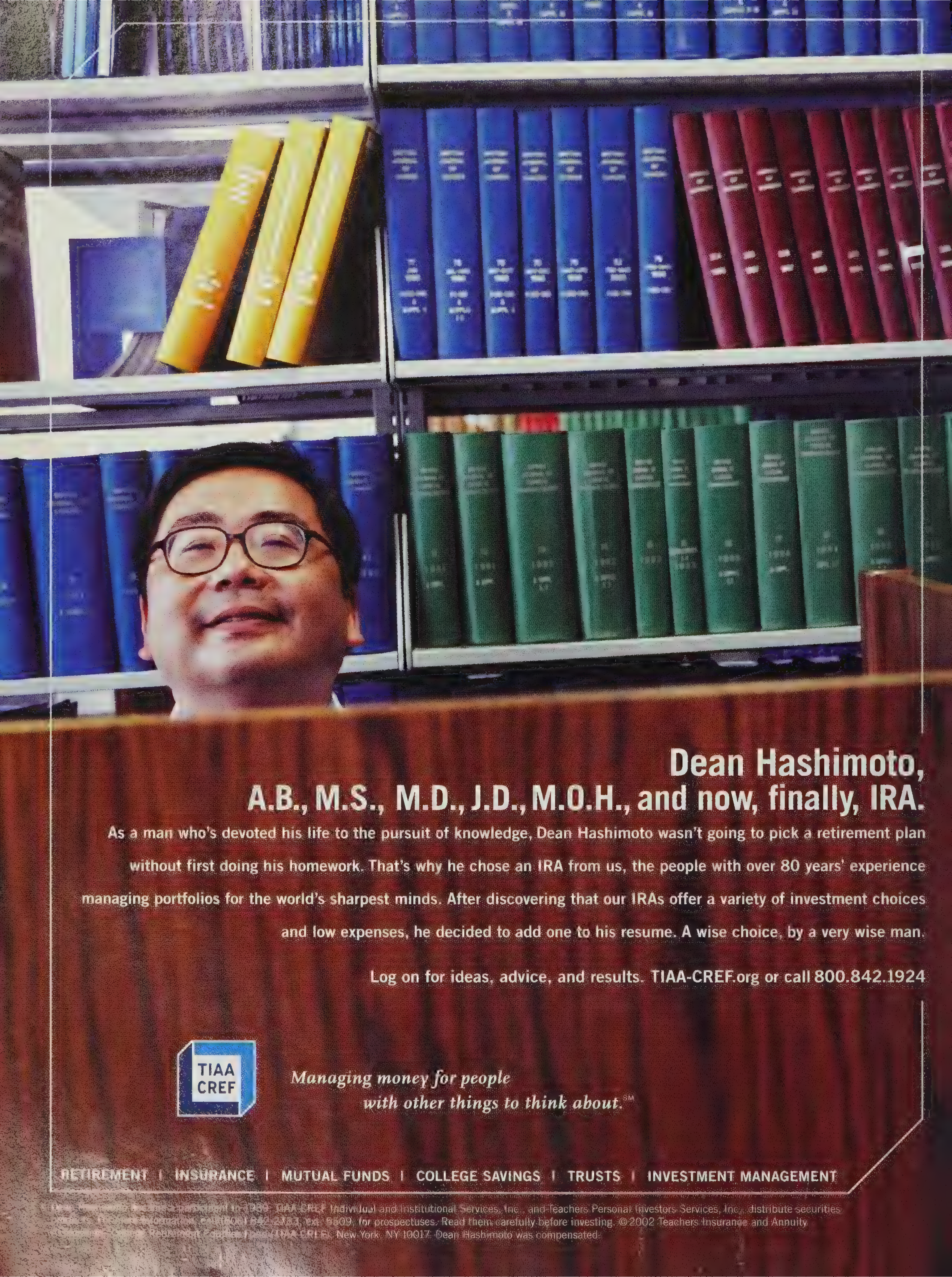
NATURAL HISTORY

4/03





Dean Hashimoto,
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NATURAL HISTORY

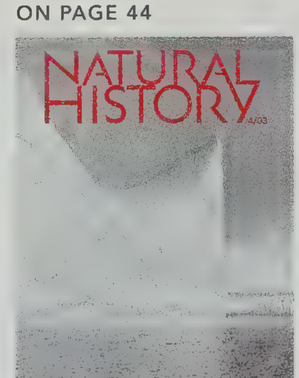
APRIL 2003 VOLUME 112 NUMBER 3

FEATURES

COVER

Lynn Davis, *Iceberg 31, Disko Bay, Greenland, 2000*

STORY BEGINS ON PAGE 44



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DEPARTMENTS

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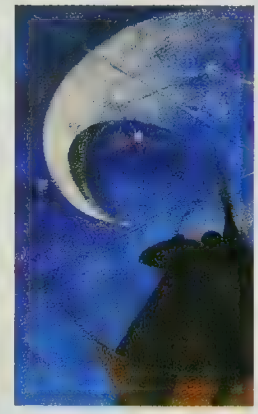

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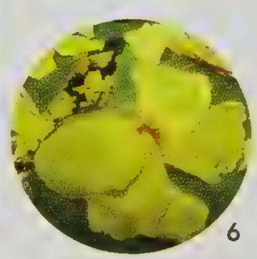

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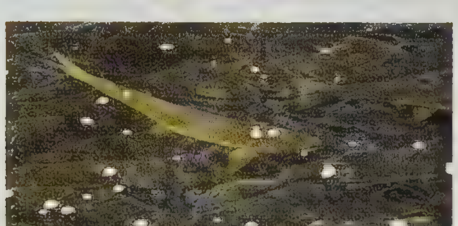

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PICTURE CREDITS: Page 14

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THE NATURAL MOMENT

So Fleeting a Spring

Photograph by Christian Ziegler

THE NATURAL MONMENT

➤ *See preceding pages*

Every year in Panama, just after the first downpour of the rainy season, the flowers of the guayacán tree *(Tabebuia guayacan)* burst open. The explosion of blossoms, whose timing coincides with the northern temperate spring, announces the end of the four- to five-month-long dry season. The downpour, and a temperature change, are thought to trigger the trees' ready buds to swell and bloom. Water plays such a critical role that, depending on rain patterns, a blossom-filled tree may be just a short distance away from a dry, unadorned one.

Native bees are drawn to the sensory delights of the guayacán, but the trees' golden-petal lucre is something of a cheat: the blossoms are not receptive to pollinators for more than a day, and they remain on the trees for only a few days before descending—like migrating butterflies—to the forest floor. Photographer Christian Ziegler found the guayacán tapestry pictured here not quite a mile from the Smithsonian Research Station on Barro Colorado Island in March. Detecting a "light, sweet smell" in the air, Ziegler said he spotted leaf-cutter ants carting away clippings of guayacán flowers—an easily digestible meal for the insects' symbiotic fungi.

Hours after dropping from the branches, Ziegler noted, the trees' saffron blossoms—even the ant's radiating trails—had darkened to yellow-brown. By the end of the day the flowers had lost all their brilliance, blending in with the leaf litter of the forest floor.

—*Erin Espelie*

UP FRONT

Life on Ice

I know, the picture on our cover this month makes it look as if we're all about to collide with an iceberg. And, truth be told, there seems plenty to be anxious about. A few weeks ago, those of us who live or work in Manhattan (the editorial staff of this magazine, for instance) thought that we had gone from yellow alert to orange, along with the rest of the country. Then the mayor reminded us that we'd been there, done that—New York City had been stuck in orange ever since the code went into effect.

Maybe it's small consolation—but things could be worse, much worse. Compared with what the Earth has undergone in its geological past, even the many human insults to our planet seem puny and fundamentally insubstantial. A few weeks ago Gabrielle Walker stopped by our offices to show us her latest report about what's hot on the geological front. A grand idea, first conceived many years ago but rejected soon afterward, has now returned with such compelling vitality—and is so well supported by the evidence of rocks all over the world—that it is stimulating new work and new thinking across an entire scientific community. Walker's story, with apologies to Laura Ingalls Wilder, is called "The Longest Winter" (page 44).

Walker isn't kidding. The "winter" in question lasted as long as 10 million years. The average annual temperature at the surface of the Earth hovered around 40 degrees below zero. Conditions were antarctic.

Most ice ages—certainly the ones people are most familiar with—are self-limiting: the ice advances, then retreats once again. The retreats may be the result of global warming by atmospheric greenhouse gases, among them carbon dioxide (CO_2). Exposed rock continually draws CO_2 out of the atmosphere and chemically locks up the carbon. During an ice age, however, the more the Earth's landmasses get covered by ice, the less rock is exposed to CO_2, and so the more CO_2 remains in the atmosphere. The atmospheric CO_2 eventually warms the Earth and reverses the march of ice.

But about 750 million years ago the continental tectonic plates haphazardly arranged themselves around the equator. That seems to have turned an "ordinary" ice age into a runaway catastrophe. Even after the polar ice began advancing, continental rock remained exposed, and it continued sucking carbon out of the atmosphere. The warming effect of atmospheric CO_2 steadily diminished. By the time the ice reached the tropics, it was too late. Ice quickly covered what was left of the Earth. Only the slow release of CO_2 by volcanoes eventually restored the greenhouse warming and enabled life to get a fresh start.

There's clearly a hopeful message in that fresh start. April, at least in the temperate zone of the Northern Hemisphere, brings mud, blossoms, new life—in short, the promise of spring. So, lest winter seem too prominent a topic for an April issue of *Natural History,* two photographers bring us their contrasting visions of renewal. Subhankar Banerjee portrays the robust glory of the vernal Arctic, which must gather all its life forces in the short months between breakup and freeze up (see "Arctic Covenant," page 58). Christian Ziegler, at the beginning of the Panamanian rainy season, documents the fragile beauty of falling blossoms that retain their color for just a few hours (see "So Fleeting a Spring," page 6).

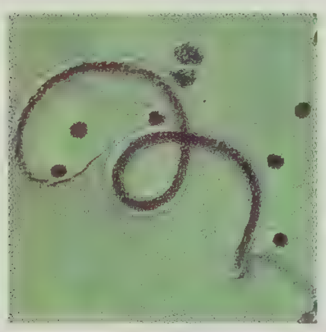
And there it is, the simplest, most bracing antidote nature has for all our anxieties: Spring will come again. Count on it.

—Peter Brown

Foresight and Hindsight

After reading T.V. Rajan's article on lymphatic filariasis ["The Worm and the Parasite," 2/03], I thought your readers might like to know of ongoing efforts to apply recent medical discoveries to the treatment and possible elimination of both filariasis and the related parasitic disease onchocerciasis.

Onchocerciasis (river blindness), characterized by incessant, debilitating itching and eyesight damage, is spread through the bite of a small black fly that breeds in rapidly flowing rivers and streams.



Larva of the parasitic worm Wuchereria bancrofti, *which causes filariasis*

Eighteen million people are infected with the disease worldwide. Adult victims can neither farm nor care for their children. Fertile bottomlands are abandoned for fear of contracting the disease, and people move to less fertile grounds, disrupting farm economies. A global effort to fight this disease includes the Carter Center, the Lions Clubs International Foundation, the World Bank, and the World Health Organization (WHO). We at the Carter Center work both in Africa and in all endemic areas in the Americas, which include Brazil, Colombia, Ecuador, Guatemala, Mexico, and Venezuela.

One oral dose a year of ivermectin (trade name, Mectizan) kills the microscopic infant worms. Merck & Co., Inc., has donated the drug to the world for as long as there is a need, and our center has enabled the delivery of more than 40 million treatments—about nine million annually. Two years ago our center's task force for disease eradication concluded that it is feasible to kill the adult worms and eliminate river blindness in the Americas if at least 85 percent of the people living in endemic areas are treated with Mectizan twice a year. A more effective treatment of adult worms will be needed to accomplish the same goal in Africa.

Fortunately, the transmission of lymphatic filariasis can also be halted by treating infected individuals just once a year. The treatment must continue for four to six years with a single-dose combination of oral medicines, most commonly albendazole and ivermectin. Bed nets also help control the transmission of the infection by mosquitoes. In patients with elephantiasis, it helps to bind the affected limbs with compressive bandages. That and, of course, the practice of proper hygiene helps reduce swelling and discomfort.

WHO ranks lymphatic filariasis as the second leading cause of permanent and long-term disability. But WHO also considers the disease eradicable—one of only six infectious diseases in that category. The Carter Center is now working in Nigeria, which has the greatest number of infected people in Africa, with the government, health authorities, and villagers. Our hope is that filariasis can be eradicated there in the next fifteen years.

Jimmy Carter
The Carter Center
Atlanta, Georgia

> *"Our hope is that filariasis can be eradicated [from Nigeria] in the next fifteen years." —Jimmy Carter*

The Edna McConnell Clark Foundation for many years sponsored research on onchocerciasis (the spectrum of infections including river blindness), including meetings that brought workers together from many countries and fields. The 1998 meeting highlighted a series of findings suggesting that *Wolbachia* were present in human filarial nematodes. Many of us left the meeting determined to find out whether the "bacteria-like bodies" seen under the microscope were in fact bacteria, what their relationship with the nematodes was, and whether they might provide a new drug target.

Since that meeting the research community has been galvanized into action. Groups in Germany headed by Achim Hoerauf and Dietrich Büttner have tested standard antibacterial drugs in animals and started a long-term trial of tetracycline for onchocerciasis in Africa. Their initial results report a prolonged and significant improvement in clinical status. (Note that it could have been otherwise: If the bacterium were just a hitchhiker, a parasite of the parasite, treatment with drugs might cure the parasite of its disease, and give rise to more human disease.)

Those promising findings have prompted a search through records to identify earlier experiments in which animals, treated with tetracycline for other reasons, were cured of filarial nematodes. Mr. Rajan suggests that such experiments were ignored because the results did not fit into a "reigning biological dogma." We would beg to differ: they were ignored because the experiments were not designed to measure the effects of drug treatment. Filarial life cycles are difficult to maintain,

and failures are common: one particular crash in the cycle of infection would not be especially noteworthy. With hindsight one can now identify the cause of the failure, but it was not evident in the original experiments.
Mark Blaxter and Katelyn Fenn
University of Edinburgh
Edinburgh, Scotland

Mr. Rajan is correct that certain preconceptions (or misconceptions) on the part of "Western" physicians may lead to the rejection of clear evidence for the efficacy of nontraditional or "nonsensical" disease treatments.

My colleagues and I were the first to identify the filarial bacteria as *Wolbachia*. Together with Norbert W. Brattig and his coworkers in Hamburg, Germany, we are now studying the effect of *Wolbachia*-derived molecules on human and canine immune cells. Results show that *Wolbachia* proteins are in part responsible for producing such mediators of immune responses as cytokines. As Mr. Rajan rightly states, these cytokines cause many of the symptoms of acute filariasis (fever, headaches, chills, and so on).

Two additional points: First, the caption to the illustration on page 32 states that the person depicted is a victim of filariasis. But the worm being removed by the patient is likely *Dracunculus medinensis,* which belongs to another superfamily. Second, *Wolbachia,* and "rickettsiae" in general, do not lack cell walls, as Mr. Rajan states.
Claudio Bandi
University of Milan
Milan, Italy

Family Ties

It is not at all clear, as Carl Zimmer writes in "Searching for Your Inner Chimp" ["The Evolutionary Front," 12/02–1/03], that human beings and chimpanzees are so "astonishingly similar" genetically.

DNA sequences are one-dimensional, inviting decontextualized comparisons, but bodies are three-dimensional. So if human and chimp DNA sequences are 1.58 percent different, is that more or less than the difference between a human femur and a chimp femur? If we put a person and a chimp next to a sea urchin, we can readily see that the two primates match up almost perfectly bone for bone, muscle for muscle, organ for organ—and that in every case the sea urchin is the odd man out. If anything, the percentage of similarity between the two species' DNA sequences *under*estimates how similar people and chimps really are in the panoply of nature.

At the other end of the scale, two DNA sequences that share no common ancestry, and are thus as evolutionarily different as they can be, still probably match at a fourth of their nucleotides by chance alone. (The DNA alphabet offers only four "letters" to choose from.) By that logic, human DNA is at least one-quarter identical to carrot DNA, in spite of the fact that we are manifestly not one-quarter carrot. Thus, for distant relatives, DNA similarities *over*estimate biological similarities.
Jonathan Marks
University of North Carolina at Charlotte

If human and chimp DNA differ by 1.58 percent, just what does that say about the difference between the two species?

In the first half of the twentieth century there was little agreement about which animal is the closest living human relative. Various advocates promoted every known ape. The case for the chimpanzee was not fully made until the work by Charles G. Sibley and Jon E. Ahlquist on DNA hybridization in 1984. They measured similarities between entire genomes, and determined that people and chimpanzees are 98.6 percent identical, virtually the same number Mr. Zimmer cites as today's consensus.

Although Morris Goodman was an early pioneer in molecular primate relationships, it was Vincent M. Sarich and Allan C. Wilson who, in 1967, applied the concept of a molecular clock, which set the stage for the current views of human evolution. Sarich and Wilson estimated that humans and chimpanzees diverged about five million years ago, an estimate now supported by much additional molecular data. *Ramapithecus,* dated at 14 million years old and declared a hominid solely on the basis of its jaws and teeth, was the first putative ancestor to be deposed by the new molecular approaches. But the lessons of history are soon forgotten. Mr. Zimmer, like many others, readily accepts the new skull from Chad, dated from between six and seven million years ago, as the earliest hominid, even though the clock for hominid evolution did not begin ticking until at least a million years later.
Adrienne Zihlman
University of California, Santa Cruz

CARL ZIMMER REPLIES: Molecular clocks are informative but not as precise as Adrienne Zihlman implies. One recent estimate for

the common ancestor of humans and chimps puts the date between 4.6 million and 6.2 million years ago; another puts it between 3.3 million and 8.3 million years ago. The age of the *Sahelanthropus* site in Chad is not certain either, because it is estimated from the dating of similar sites. That's why the discoverers of the fossil maintain only that it can be tentatively dated to between six million and seven million years ago. Given the overlap and fuzziness of these estimates, *Sahelanthropus* is not ruled out as a hominid.

Misting in Action

In "Grain Gain," ["Samplings," 2/03], Stéphan Reebs states: "Methane is the second most damaging greenhouse gas in the atmosphere." Indeed, methane is the second most damaging greenhouse gas governed by the Kyoto Protocol, but the major greenhouse gases in the atmosphere are, in order of their warming effect, water vapor, carbon dioxide, and then methane. Like carbon dioxide and methane, water vapor has many anthropogenic sources, from the burning of hydrocarbons to the excess evaporation from reservoirs, lakes created by dams, and rice paddies.

W.D. Benton
Albuquerque, New Mexico

Reading the Tree Leaves

Egbert Giles Leigh Jr. and Christian Ziegler ["Biosphere III," 2/03] make the important observation that the interplay between plant and animal species is central to shaping the diversity of tropical forests. Their study of the fragmentation of a Panamanian forest shows that the elimination of some animal species can dramatically alter the survival of certain plants and the composition of species.

Unfortunately, similar "experiments" are taking place throughout the Tropics: more than 60,000 square miles of forest are lost each year, creating a patchwork of unconnected fragments. Studies such as Messrs. Leigh and Ziegler's underscore the value of preserving large tracts of land, and of considering such a web of interactions in making decisions about forest management and conservation. Now is the time to make these critical land-use decisions before too much of what they aptly call a magic web is lost.

Phyllis D. Coley and Thomas A. Kursar
University of Utah
Salt Lake City, Utah

Messrs. Leigh and Ziegler offer an intriguing discussion of the unintended

MULTITASKING If you're lucky enough to have a backyard vegetable garden this summer, pull up a bean plant (or any other legume) and take a look at its roots. The little swellings you'll see are nodules formed by the plant and inhabited by bacteria. But don't be alarmed: there's no disease. The plant needs nitrogen to make proteins, but the nitrogen in the plant's environment takes a "raw" form the plant cannot use. That's where the bacteria come in: they "fix" the nitrogen in a molecular form that makes it available to the plant. In exchange, the plant supplies the bacteria with sugars and other compounds.

The nitrogen-fixing partnership has long been the subject of intense scientific study—if only because so many of the world's protein-rich crops are legumes: alfalfa, soybeans, and peas, to name a few. Now Rieko Nishimura, a molecular biologist at the University of California, Berkeley, and several of her colleagues at Japanese universities have provided investigators with a new tool: a mutant form of the legume *Lotus japonicus*, a "model" organism well known to plant geneticists around the world. The mutant form is called astray because it grows long horizontal roots that, with respect to gravity, have "gone astray."

More to the point, the astray form generates many more nodules than the plant's nonmutant form, and it makes them early in its life. Astray has aboveground abnormalities as well. For example, its stem is elongated and its color a washed-out green—typical features of plants that lack access to light. Thus the *astray* gene is involved both in the plant's responses to light, an attribute of the aboveground world, and in the formation of roots and nodules underground. And the gene's multiple talents offer a window into the evolution of nodulation in legumes: certain proteins that were operating in the light of day were co-opted for work within the darkness of the soil. ("A Lotus basic leucine zipper protein with a RING-finger motif negatively regulates the developmental program of nodulation," *Proceedings of the National Academy of Sciences* **99**:15206–10, November 12, 2002)

EAU DE DANGER Do animals smell fear? Mostly the answer is no. Sight, not smell, is what reveals a frightened creature's (or person's) emotional state. But for animals in a watery environment, the smell of fear does indeed act as a strong signal—albeit more as a warning to potential victims than as a giveaway to predators.

It is known that frightened crayfish, crabs, fish, and tadpoles spurt ammonia in their urine and through their gills. For neighboring animals—even unrelated species—the fluids serve as a kind of universal "disturbance cue," causing them to seek cover or become more circumspect, even though they may not be able to sense the predator directly.

Brook charr can tune in to the smell of fear.

Now two biologists at the University of Saskatchewan in Saskatoon have shown that disturbance cues can even lead some fish to identify previously unknown predators. Reehan S. Mirza and Douglas P. Chivers scared young brook charr (also known as brook trout) by striking the water surface of the charr's tank with a fake heron head. Then they collected a sample of the water. They also collected water from tanks containing predatory northern pike. Then they subjected two new groups of charr to a few ounces of water from the pike tanks. One of the new groups (the experimental group) also received a few ounces of the water from the tank that had been disturbed by the fake heron head. The second new group (the control group) received the same amount of water from a tank containing charr that hadn't been disturbed.

When the charr in the experimental group then encountered a pike in a test tank, they gave the unfamiliar predator a wider berth and avoided capture for a longer time than did the charr in the control group. Mirza and Chivers conclude that when charr detect disturbance cues, they pay attention to other odors in the vicinity and thereafter treat those odors as suspicious, and so they are more alert to potential predators and can survive longer. ("Behavioural responses to conspecific disturbance chemicals enhance survival of juvenile brook charr, *Salvelinus fontinalis*, during encounters with predators," *Behaviour* **139**:1099–1109, 2002)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*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Reaching for the Stars

Instead of counting smart bombs, perhaps we should count smart scientists.

By Neil deGrasse Tyson

In the months since the space shuttle *Columbia*'s fatal reentry through Earth's atmosphere, it seems that everyone has become a NASA critic. After the initial shock and mourning, no end of journalists, politicians, scientists, engineers, policy analysts, and ordinary taxpayers began to debate the past, present, and future of America's presence in space. Although I have always been interested in this subject, my recent tour of duty with the President's Commission on the Future of the U.S. Aerospace Industry has further sharpened my senses and sensitivities.

Amid the occasional new arguments on the op-ed pages and TV talk shows were questions that get rolled out with every new woe in the space program: Why send people into space instead of robots? Why spend money in space when we need it here on Earth? How can we get people excited about the space program again?

Yes, excitement levels are low. But lack of enthusiasm is not apathy. In this case, the business-as-usual attitude shows that space exploration has passed seamlessly into everyday culture, so most Americans no longer even notice it. We pay attention only when something goes wrong.

In the 1960s, by contrast, space was an exotic frontier—traversed by the few, the brave, and the lucky. Every gesture NASA made toward the heavens caused a splash in the media—the surest evidence that space was still unfamiliar territory.

For many, particularly for NASA aficionados and all of the people engaged in the aerospace industry, the 1960s was the golden era of American space exploration. A series of space missions, each more ambitious than the one before, led to six lunar landings. We walked on the Moon, just as we said we would. Surely Mars was next. Those adventures sparked an unprecedented level of public interest in science and engineering, pumping eager, inspired students through the entire U.S. educational pipeline. What followed was a domestic boom in technology that would shape our lives for the rest of the century.

A beautiful story. But let's not fool ourselves into thinking we went to the Moon because we're pioneers or explorers or selfless discoverers. We went to the Moon because Cold War politics made it the militarily expedient thing to do.

Let's not fool ourselves. NASA went to the Moon because of Cold War politics.

In 1961, just weeks after the Soviet cosmonaut Yuri Gagarin became the first person to orbit Earth, President John F. Kennedy told Congress:

> I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.

But most people have forgotten the rest of his speech. Kennedy never suggested the Moon landing be accomplished for its own sake. He was issuing a powerful appeal to vanquish Communism:

> If we are to win the battle that is now going on around the world between freedom and tyranny, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere, who are attempting to make a determination of which road they should take.

Clearly the president knew that although bravery may win battles, science and technology can win wars. And Kennedy was hardly the first leader to call for an expensive military program.

But what about discovery for its own sake? Are the scientific returns on a manned mission to Mars inherently important enough to justify its costs? After all, any foreseeable mission to Mars will be long and immensely expensive. But the United States is a wealthy nation. It has the money. And the technology is imaginable. Those aren't the issues.

Expensive projects are vulnerable because they take a long time and must be sustained across changeovers in political leadership as well as through downturns in the economy. Photographs of homeless children and unemployed factory workers juxtaposed with images of astronauts frolicking on Mars make a powerful case against the continued funding of space missions.

A review of history's most ambitious projects—the ones that have garnered an uncommonly large fraction of a nation's gross domestic product—demonstrates that only three goals have won such support: defense (the Great Wall of China); the promise of eco-

nomic return (the voyages of Columbus and Magellan); and the praise of power (the pyramids of Egypt). And for expensive projects that fulfill more than one of these functions, money flows like beer from a freshly tapped keg. The 44,000 miles of U.S. interstate expressways make a crisp example. Conceived in the Eisenhower era to move matériel and personnel for the defense of the nation, that network is also heavily used by commercial vehicles. That's why there is always money for roads.

In the current space program the empirical risk of death remains high. With two lost shuttles out of 113 launches, an astronaut's chances of not coming home are about 2 percent. If your chances of death were 2 percent every time you drove to the Piggly Wiggly, you would never drive your car. To the *Columbia* crew, however, the return was worth that risk.

I'm proud to be part of a species whose members occasionally and willingly put their lives at risk to extend the boundaries of their existence. Such people were the first to leave the cave and see what was on the other side of the cliff face. They were the first to climb the mountain. They were the first to sail the ocean. They were the first to touch the sky. And they will be the first to land on Mars.

But somebody has to write the check. We've made it out of the cave and up the mountain. Now exploration costs real money. When nobody writes the check, we stall on the last breached frontier.

Actually, there *may* be a way to keep going places. But it involves a slight shift in what the government usually calls national defense. If science and technology can win wars, as the history of military conflict suggests, then instead of counting our smart bombs, perhaps we should be counting our smart scientists and engineers. And there is no shortage of seductive projects for them to work on:

Rufino Tamayo, *El hombre*, 1953

- We should search Mars for fossils and find out why liquid water no longer runs on its surface.

- We should visit an asteroid or two, and learn how to deflect them. If one is discovered heading our way, how embarrassing it would be for us big-brained, opposable-thumbed humans to meet the same fate as the proverbially pea-brained dinosaurs.

- We should drill through the kilometers of ice on Jupiter's moon Europa and explore the liquid ocean below for living organisms.

- We should explore Pluto and its newly discovered family of icy bodies in the outer solar system, because they hold clues to our planetary origins.

- We should probe Venus's thick atmosphere to understand why its greenhouse effect has gone awry, giving rise to a surface temperature of 900 degrees Fahrenheit.

No part of the solar system should be beyond our reach; we should deploy both robots and people to get there (robots make poor field geologists). And no part of the universe should hide from our telescopes; we should launch them into orbit and give them the grandest vistas for looking back at the Earth and at the rest of the solar system.

With missions and projects such as those, the U.S. can guarantee itself an academic pipeline bursting with the best and the brightest astrophysicists, biologists, chemists, engineers, geologists, and physicists. And they will collectively form a new kind of "missile silo"—filled with intellectual capital—ready to come forward whenever they are called, just as the nation's best and brightest have always come forward in times of need.

For the U.S. space program to die along with the crew of the space shuttle *Columbia*—because nobody is willing to write the check to keep it going—would be to move backward just by standing still.

Astrophysicist Neil deGrasse Tyson is the director of the Hayden Planetarium in New York City. He was a presidential appointee to the twelve-member Commission on the Future of the U.S. Aerospace Industry (www.aerospacecommission.gov), whose final report was submitted to the White House in November 2002.

Leftovers from an ursine banquet: nutrients from the parts that were eaten will also fertilize the plants . . . indirectly.

How Bears Feed Salmon to the Forest

Trees get the table scraps from a fish dinner.

Story and Photographs by Robert S. Semeniuk

Wearing night-vision goggles, Thomas E. Reimchen maneuvers our inflatable boat around rocks, deadfalls, and barnacles as we pick our way in the dark up an estuary in Canada's Pacific Northwest. In our wake we leave brilliant bursts of bioluminescence, as schools of fleeing salmon agitate unicellular algae called dinoflagellates. Why the "dinos" emit light is open to interpretation. One explanation, Reimchen tells me, is that the light attracts fish that eat zooplankton such as copepods, which are predators of the dinoflagellates.

A biologist at the University of Victoria in British Columbia, Reimchen specializes in predator-prey interactions. We are here to observe black bears catching spawning salmon (the bears get most of their catch in the dark). The field study is part of an investigation born more than a decade ago at Bag Harbour in the Queen Charlotte Islands. One day in 1992, as Reimchen was sitting under giant Sitka spruce trees and looking at half-eaten salmon carcasses strewn about on the forest floor, he realized that the abundance of carcasses and the abundance of giant trees adjacent to the river was probably no coincidence. Ever since that moment, he has collected evidence that the autumn return of salmon from the Pacific Ocean to the streams of their birth is much more than just the annual migration of fish. The run of salmon constitutes a major flow of marine nutrients into estuaries and coastal watersheds.

Reimchen estimates that before the expansion of commercial fishing and industrial logging in the twentieth century, when salmon were more abundant throughout coastal streams, each of the 30,000 black bears living in the salmon watershed may have caught on average 500 fish a year. If half of each carcass was left uneaten on the forest floor (a reasonable estimate), he figures the nutrient transfer into the rainforest amounted to more than 25,000 tons a year, of which 3.4 percent was nitrogen.

And salmon carcasses are by no means the only way bears spread salmon-derived nitrogen to the terrestrial ecosystem. Other field biologists, such as Grant V. Hilderbrand, formerly of the Alaska Department of Fish and Game, and his colleagues, have documented two other major means: urine and feces. Hilderbrand, who studied brown bears in Alaska, maintains that urine is particularly important. Bears consume salmon in the late summer and fall to accumulate the fat reserves they will need to hibernate—and that females will need to birth and provide milk for their cubs. Although some of the nitrogen from the salmon goes into building muscle tissue and meeting other physiological demands, the bears' fat tissue is virtually nitrogen-free. Consequently, much of the nitrogen in the salmon protein is excreted. "The bottom line," Hilderbrand says, "is that if the bears leave half of each carcass in the forest, the other, eaten half also is ultimately deposited in the forest as well."

Reimchen's boat carries us out of the salty estuary and up the Klekane River into the conifer rainforest of the coastal mainland of British Columbia. After the boat has been safely tied up at the bank, Reimchen leads me and two of his coworkers, Deanna D. Mathewson, also of the University of Victoria, and Daniel R. Klinka, a graduate student of Reimchen's, along a creek into the pitch-black woods. To avoid surprising any bears, Reimchen trudges steadily for-

ward, uttering low guttural sounds. Then, at the edge of the creek we stop and wait quietly; I scan the forest on the opposite bank.

"There is a bear downstream walking towards us," someone whispers softly. The splash of the footsteps sounds closer than the animal appears through my night-vision goggles. The bear lunges forward, crashes through the water, but misses a fish. The bear moves upstream slowly, to within perhaps fifty feet of us, and takes another lunge. Again, no catch. On its fourth try, the bear succeeds. I hear the crunch of fish skull, and the bear disappears into the forest with a big chum salmon in its mouth.

Black bears favor the bigger chum salmon to the smaller pink salmon; they are more apt to eat pink salmon in the stream, and usually carry chum salmon into the forest. At Bag Harbour Reimchen had predicted that bears would take larger and thus more valuable catch farther into the forest, where other bears and scavengers would be less likely to interfere. That led him deeper into the forest in search of carcasses. Occasionally he found them as far as 200 yards away from the streams.

Some bears have a taste for salmon brains; others eat everything but the fish's testicles.

The bear returns in about fifteen minutes and starts fishing again, by swatting and grabbing. Bears exercise various techniques. Some patiently wait in the shallows and then just flop into the water on their bellies. Reimchen says that by day at Bag Harbour, black bears would just wade in and snorkel, or search overhangs and logs, and catch fish without any great motion. Salmon are more quiescent at night, he adds, and can readily be approached in the water. "At night I can pick up big chum salmon; as long as I don't take them out of the water, or squeeze them too hard, they allow me to hold them."

Reimchen notes that black bears catch more male fish than females. "Males are always darting around," he notes, "fending off other males and chasing females," whereas females are

A grizzly catches pink salmon in Knight Inlet of the mainland coast, near Vancouver Island

more likely to hide in the shadows, say, under a log. The distinguishing hump on the male's back may also make it easier to see or catch [*see "Fin Tuning," below*].

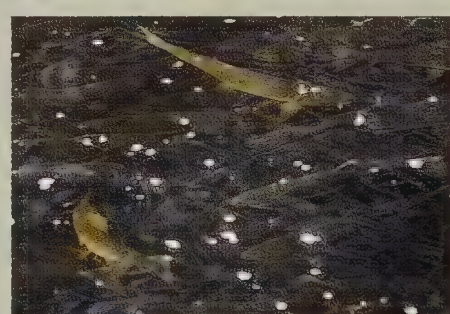
Some bears eat only parts of the fish—they bite out the brain, or strip out just the eggs. Other bears leave nothing except a pair of intact testicles draped over a rock or a mossy log. The sperm are made up mainly of nucleic acids (DNA), and they are metabolically hard to digest because they may yield high levels of nitrogenous toxins. In contrast, eggs are mainly yolk—in other words, oils. Often bears delicately skin and eat only the fattest parts of the fish, leaving the rest to be scavenged successively by eagles, martens, ravens, crows, gulls, beetles, and fly larvae. Even deer and squirrels feed on salmon carcasses.

Reimchen and his colleagues examine, weigh, and take a broad range of data about each carcass: lower jaw length; body length; sex; weight of testes, or the number of eggs in the

Fin Tuning

By Scott M. Gende and Thomas P. Quinn

Bears that live near salmon streams and spawning grounds tend to grow larger, have more cubs per litter, and belong to denser populations than do bears without access to salmon. No big surprises there. But what difference do the bears make to the salmon? Does being the prey of bears measurably affect salmon ecology, behavior, or evolution? Three criteria must hold for the answers to be yes. First, bears have to kill a "high enough" proportion of a salmon population. Second, predation can't be random; some fish must be favored, or ignored, according to some morphological or behavioral trait. Third, and most important, predation must influence salmon fitness, or in other words success at reproduction. Because salmon returning to freshwater streams will soon die anyway, whether killed by bears or not, the answers are far from obvious.


Pink salmon in Knight Inlet

Having observed the interactions of bears and salmon for many years, we have concluded that the three criteria can be met only at small streams. First, in small streams, bears can kill a high proportion of the salmon; the fishing requires less effort there than it does in wider and deeper streams.

Second, perhaps because of the greater visibility or "catchability" of large fish in shallow water (or because of the simple preferences by the bears) large salmon (at least in small streams) are more likely to be killed than smaller ones. By targeting the large fish, bears may be maximizing the energy they gain from food, compared with the energy they spend in catching the fish.

Third, in small streams bears preferentially kill salmon that have not yet spawned. The reason is that salmon do not eat once they enter freshwater; instead, they draw on their own stores of fat, or lipid, as well as protein, for the energy to migrate upstream and reproduce. Consequently, the longer a salmon has been in a stream, the lower its energy content. Salmon just entering streams carry as much as 90 percent more lipid and 50 percent more protein than do salmon that have spent some time on the spawning grounds and are near death. Thus the energy reward for the bears is much greater if they kill a salmon that has just entered a stream—particularly a female salmon, whose lipid-rich eggs are the bears' choicest meal. Bears may be able to distinguish energy-rich fish by their appearance because the loss in lipid and protein also leads to a loss of skin color and an increase in body fungus. By contrast, in larger or more structurally complex streams, bears do not or cannot selectively target the larger fish or the most recent arrivals.

The results of bear predation are evident in the salmon themselves. Compared with the salmon in large streams, the ones in small streams where predation is high tend to be smaller and to spawn their eggs sooner after entering the stream.

Another effect of the bears is reflected in the dorsal humps of male sockeye and pink salmon: they are smaller than the humps of salmon not exposed to bears. Usually—even accounting for differences in body length—males with relatively large humps win out in the competition for females. The hump may serve the practical purpose of making the fish's profile too fat for another male to bite, but it is also used in display. To some extent, too, females may prefer a larger hump in their mate. Other things being equal, a larger hump would seem to be the way to go.

The back-to-belly thickness of a male sockeye salmon may range from four to ten inches. Yet some of the streams they spawn in can be as shallow as three and a half inches deep. In those streams, the larger the hump, the more it will stick out of the water. Such a hump may be more readily visible to bears, and it may make maneuvering harder for the fish (in small streams, stranding is a more severe problem for large-humped males than for small-humped ones). Either way, the large-humped males are the ones more easily captured. Here, too, bear predation becomes a powerful source of natural selection, countering the selective pressures that otherwise would maintain a large hump.

Scott M. Gende is an ecologist at the Pacific Northwest Research Station in Juneau, Alaska. Thomas P. Quinn is a professor in the School of Aquatic and Fishery Sciences, University of Washington in Seattle.

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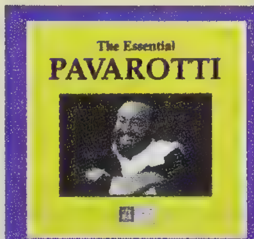

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body cavity and on the ground; position of the carcass and its distance from the stream; body condition and intactness; presence or absence of the brain. In addition, the biologists collect tree cores and plant-tissue samples in as many watersheds as possible.

During his initial investigations in Bag Harbour, Reimchen had reckoned he could gauge historical trends and fluctuations in the flow of salmon by examining the yearly growth rings of trees. The number of salmon entering Bag Harbour has varied enormously during the past half-century, ranging from 500 to 35,000 a year. Presumably, Reimchen reasoned, trees grew faster, and their growth rings became thicker, in the years in which salmon were more abundant. But he didn't know how he could rule out some independent external factor: after all, tree growth might be largely determined by rainfall.

Then a colleague, Joseph Rasmussen, a biologist at McGill University in Montreal, suggested that Reimchen measure the relative proportions of nitrogen isotopes in the tissue of forest plants. Specifically, Rasmussen noted, Reimchen should measure the proportion of nitrogen that is made up of the isotope nitrogen 15. (By far the most common form of atmospheric or oceanic nitrogen is made up of the isotope nitrogen 14, so called because each atomic nucleus of nitrogen 14 contains a total of fourteen protons and neutrons.) Nitrogen 15, which has an extra neutron, becomes more concentrated in marine life-forms at progressively higher levels of the food chain. Hence in salmon, a fourth-level consumer, the concentration of nitrogen 15 is relatively high, compared with its concentration in the air. That makes it fairly straightforward to measure the relative contribution marine nutrient sources such as salmon make to trees and other plants.

Nitrogen isotopes in tree rings record changes in the annual run of salmon.

Although other investigators were already measuring nitrogen 15 to estimate the contribution of salmon-derived nitrogen to aquatic habitats, Reimchen was one of the first to apply the procedure in terrestrial plants. For example, to isolate the contribution of salmon to the forest nutrient mix, he has compared the nitrogen-15 proportions in vegetation growing above and below waterfalls that are barriers to migrating salmon. Similarly, he has looked at the proportion of nitrogen 15 to see if it falls off as one moves inland from the salmon-charged

The rainforest on Princess Royal Island, northwestern British Columbia, gains marine nutrients when salmon return to their natal waters to spawn.

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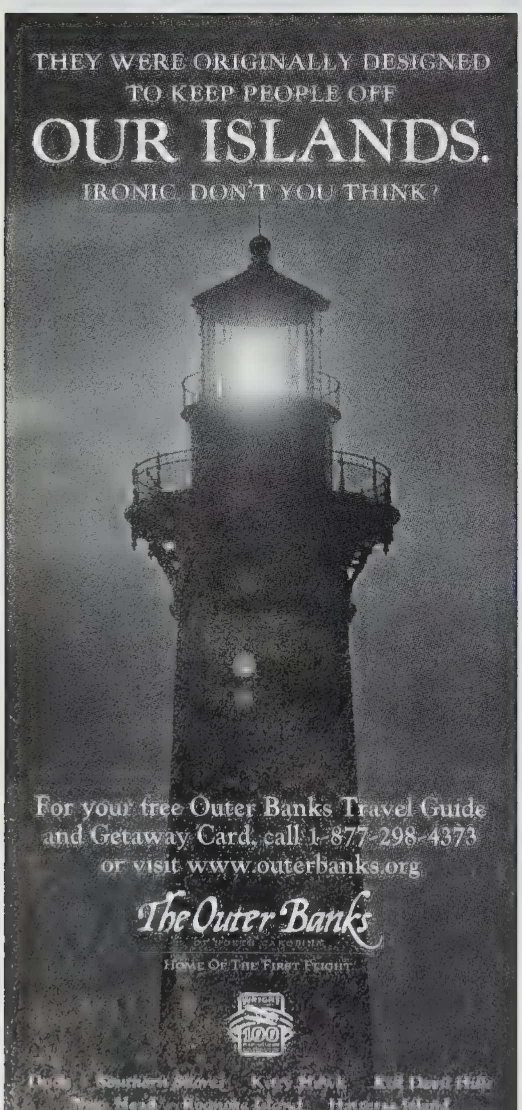

streams. The results have confirmed that trees closest to the salmon streams draw the largest share of marine nutrients. In fact, fully half of the nitrogen in some old-growth trees near salmon streams comes from salmon.

But Reimchen's goal has remained the ambitious one he started with: to chronicle the annual ups and downs of marine-derived nitrogen. To do that, he had to measure the proportions of the nitrogen isotopes in each growth ring. Together with the age of the ring, he reasoned, that difficult measurement would give him the data he sought.

Reimchen and his colleagues set out to drill and extract half-inch cylindrical cores from old-growth cedar, spruce, and hemlock trees. At first, however, no mass spectrometer could measure the trace quantities of nitrogen 15 present in the minute wood samples cored from a single growth ring. After four years of false starts, though, Reimchen found a laboratory in Davis, California, that has been systematically able to resolve differences in nitrogen-15 levels in samples as small as one—or at most just a few—tree rings. As one might expect, the greatest annual swings in concentration occur in the trees closest to the streams. Independent historical data of salmon abundance correlates well with nitrogen-15 signatures in rings during the past fifty years. Because it takes a year or so for nitrogen to be incorporated into a tree, however, the nitrogen-15 fluctuations lag the fluctuations in salmon by one to three years. Reimchen's team has also found high total nitrogen levels in the rings of trees nourished by salmon, suggesting that such trees grow relatively fast and large. The investigators are currently examining watersheds where the salmon populations have dropped off sharply, and expect to document the general chronology of those changes.

The records of early European settlers—even the memories of Native American elders—recall rivers that ran with thousands of salmon, rivers where the salmon have now become rare or have even vanished. Many such stories are largely rejected by fishery biologists as exaggerations. After all, how could anyone say whether salmon existed in some now-quiet stream, sometime in the past? "Now, for the first time, we have a method of answering that question," says Reimchen—and perhaps of determining the abundance of such salmon in the past.

Reimchen's work is not the only window into that past. Hilderbrand and his colleagues analyzed hair specimens from grizzly bears that existed in Oregon's Columbia River Valley until 1931. The investigators have shown that an average of 58 percent of the grizzlies' diet came from salmon. Even grizzly bears as far as 800 miles from the ocean consumed salmon. Reimchen's research could add a new dimension to those findings. Mapping trees enriched with salmon nutrients would reveal vital arteries that link marine and terrestrial habitats; in principle, that could be done with remote sensing by satellite.

As we come to the end of our nighttime observations, Reimchen speaks about how his work feeds into the formulation of conservation policies. "People act as if they harvest the surplus, and are the only harvesters. They think that all the dead fish in the stream are wasted." But the work of Reimchen and other investigators shows that not only do salmon replenish the forest; they also revitalize streams and estuaries with carbon, nitrogen, phosphorous, and other minerals. Among salmon themselves, the circle of life is particularly intimate: nearly half of the nutrients consumed by juvenile salmon comes from their dead parents. "In ecosystems there is no surplus," says Reimchen. "Everything is used."

Robert S. Semeniuk is a freelance writer and photojournalist based in Bowen Island, British Columbia. For further information about the work of Reimchen and his colleagues, see web.uvic.ca/reimlab/.

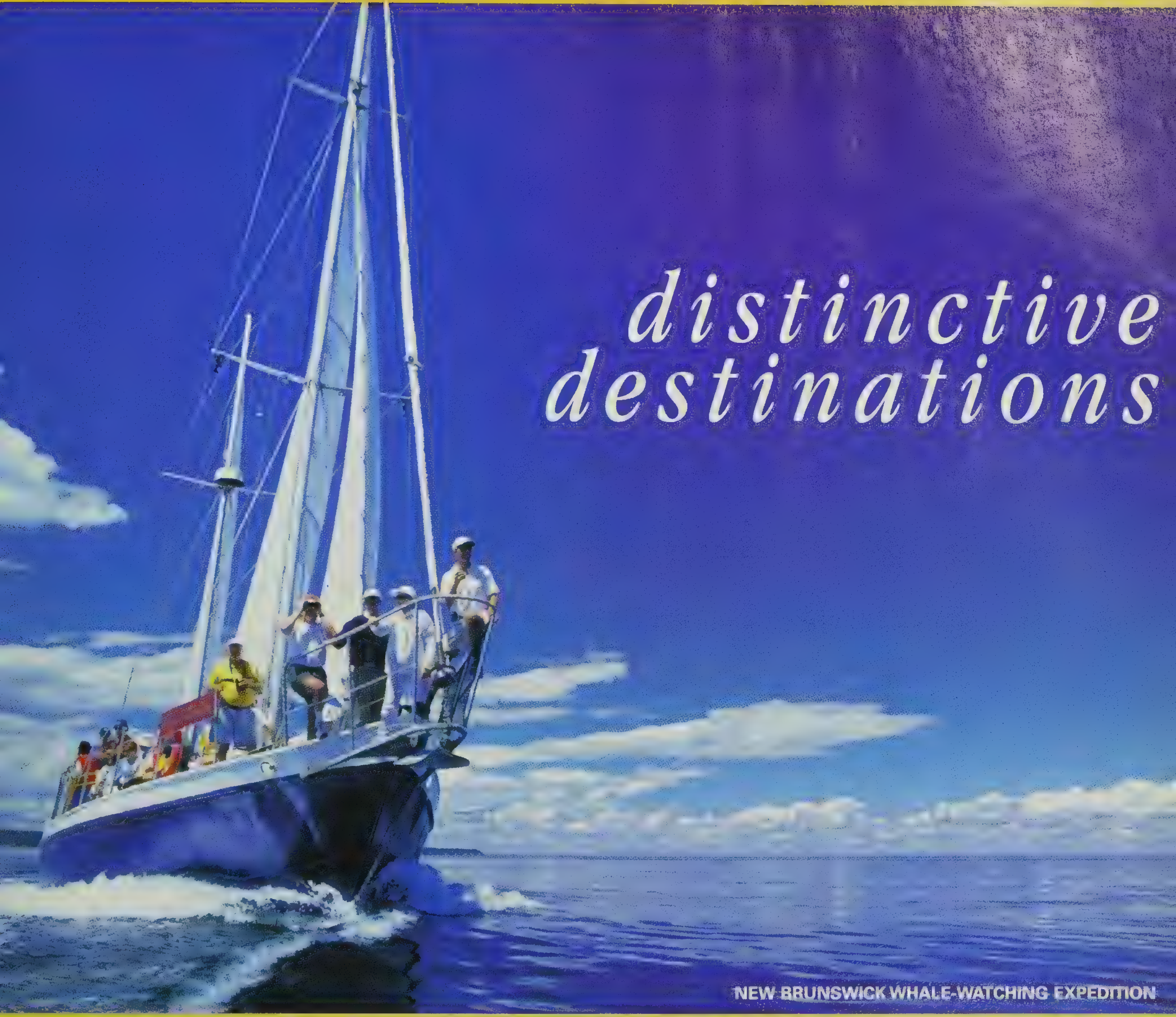

Photo: New Brunswick Tourism and Parks

This spring, treat yourself to a trip of a lifetime!

- Set sail to whale-watch in the Bay of Fundy
- Ride the roaring rapids of West Virginia
- Walk on a glacier in Norway
- Bird-watch in the Caymans
- Race a steamboat down the Mississippi
- Look for white-faced capuchins in the Costa Rican jungle
- Escape to a private island along the Georgia coast
- Cruise down the Rhine
- Visit a penguin colony before sailing around the legendary Cape Horn!

NEW BRUNSWICK

FROM BREATHTAKING VIEWS TO SPECTACULAR NATURAL SITES AND PRESERVED SANCTUARIES, THERE'S A WORLD OF WONDER WAITING FOR YOU NEXT DOOR IN NEW BRUNSWICK, CANADA!

TOP: KAYAKING UNDER THE ARCH AT THE HOPEWELL ROCKS IN THE BAY OF FUNDY; BOTTOM: DANCERS AT KINGS LANDING HISTORICAL SETTLEMENT

New Brunswick, Canada has so many wonders waiting to be experienced and explored! New Brunswick's Bay of Fundy is One of the Marine Wonders of the World. Twice a day the world's highest tides rise and fall almost 48 feet (that's equivalent to a four-story building!). Walk on the ocean floor and just six hours later, kayak above the very same spot! Paddle under the arch at the famous Hopewell Rocks... towering rock formations carved by millions of years of surging Fundy tides! Set sail to see all kinds of whales. Playful Humpbacks, giant Finbacks, and even the rare Right Whale! Thrill at the sight of countless shorebirds reeling and diving, and explore the coast from the amazing Fundy Trail.

But the wonder doesn't stop there

in New Brunswick! Take a pontoon boat tour between the towering cliffs of Grand Falls Gorge! Find new inspiration touring some of Earth's oldest mountains on New Brunswick's Appalachian Range Route! Or visit preserved sand dunes such as the Irving Eco-Centre, La Dune de Bouctouche, for a tranquil tour through our one-of-a-kind natural wonders!

One thing is for certain in New Brunswick... there's never a question of what you can do... only what you can do *next!* The province is home to two of Canada's National Parks! Head to Kouchibouguac National Park and take a seaside stroll along its endless sandy stretches! In Fundy National Park you can hike and camp just moments away from this renowned natural phenomenon.

Got a day? Try our incredible Day Adventures! Kayak to see a sandbar full of seals, explore caves, learn to dip candles or how to catch and cook a lobster! There are also our amazing Top Attractions! From visiting the fictional village of Le Pays de la Sagouine to crossing the world's longest covered bridge in Hartland, it's the "A" list of everything there is to see and do in the province! And no stop would be complete without visiting the towns and villages that make up Hometown New Brunswick!

New Brunswick's landscape is a rich ethnic tapestry comprising Aboriginals, Brayonne, Irish, Scottish, Loyalist, and Acadian cultures! Experience Canada's oldest Irish Festival! Live like a Loyalist at Kings Landing Historical Settlement! Or discover the meaning of our famous French Acadian *joie de vivre* (joy of life) as you sing along to the dinner theater at the Village Historique Acadien!

Shop for unique local crafts like blown glass, pottery as well as sculptures and paintings by renowned Maritime artists! Visit distinctive Economuseums like The Olivier Soapery, where you learn both the history and the art of making soap (the gift shop has a huge variety of products!).

Visitors from the United States are always amazed at how affordable it is to travel in New Brunswick! It's no wonder... with such a favorable exchange rate, two US dollars can equal up to as much as three Canadian dollars! That means you can explore more for a lot less!

New Brunswick, Canada... where so many wonders welcome you!

Visit us on-line at www.TourismNewBrunswick.ca/natural or call 1 800 561-0123 for your FREE New Brunswick Vacation Planning Kit! Check out our neighbors at www.TourismNewBrunswick.ca/Neighbours.

TOP: PONTOON BOAT EXCURSION THROUGH GRAND FALLS GORGE; ABOVE: SUCCULENT LOBSTER FEAST; BELOW: CART RIDE AT THE VILLAGE HISTORIQUE ACADIEN

Photos: New Brunswick Tourism and Parks


Walk on the
Ocean Floor...
In New Brunswick, Canada's Bay of Fundy
Just the Beginning of the Wonder Next Door!
WIN a Vacation in New Brunswick Canada!
TURN THE PAGE FOR CONTEST DETAILS
Uncover the Eco-treasures of Some of the Continent's
Most Distinctive Dunes
and Our Discovery Beaches!
Visit the Irving Eco-Centre, La Dune de Bouctouche, and tour the botany and biology of one of the last sand dunes on the northeastern coast of the continent. Search for fossils and seashe on our Discovery Beaches… the undiscovered treasures of New Brunswick's over 2,065 kilometres (1,200 miles) of coastline.
Irving Eco-Centre, La Dune de Bouctouche, Saint-Édouard-de-Kent
Experience the
Bay of Fundy...
One of the Marine Wonders of the World!
The world's highest tides… they happen here twice every day! See so many different species of whales! Walk on the ocean floor and only hours later, kayak above the same spot! It's our Bay of Fundy… an incredible natural phenomenon… it's just the beginning of the wonder in New Brunswick, Canada!
Grand Manan Island
Tour Miles of the Maritimes'
Most Spectacular Rivers!
The St. John River reaches from the Bay of Fundy up beyond the breathtaking Grand Falls Gorge! The legendary Miramichi calls fly fishers from around the world to challenge miles of salmon-fishing paradise. On the Restigouche, you can canoe through the unspoiled wilderness for days on end.
Grand Falls Gorge, Grand Falls/Grand-Sault
Find New Inspiration Touring Some of
Earth's Oldest Mountains!
The Appalachians are a mantle of wondrous natural beauty and you'll be awed by their untouched vastness. Canoe the lakes and rivers that the mountains frame. Hike endless trails to lookouts that are not only breathtaking… they are inspiring.
Appalachian Range


A Culture as Vibrant as Our Colourful and Storied Past!
Come for the humour of our lively dinner theatre, Le Pays de la Sagouine, and visit the Village Historique Acadien – a living 18th-century French village! Come for traditional cuisine, folk tales, and old-fashioned hospitality. And for the dramatically beautiful Acadian coast… the perfect setting for our extraordinary Acadian culture.
Village Historique Acadien, Caraquet
The Acadian coast is also home to hundreds of thousands of birds as they congregate in places such as Lamèque's Ecological Park of the Acadian Peninsula, and Irving Eco-Centre, La Dune de Bouctouche. An uncommon culture – an unforgettable vacation… and it's right next door, in New Brunswick, Canada!
1604-2004 Celebrations
In 2004, New Brunswick will celebrate the 400th anniversary of the first French settlement in North America, which occurred on St. Croix Island. Thus began the great Acadian adventure.
Grande-Anse
The Hopewell Rocks, Hopewell Cape, at low tide 6:25 AM
9:30 AM
1:00 PM
Tide times vary daily.
Succulent Seafood Served Up From the Sea!
Succulent Seafood, World-class Cities & Wonderful Seaside Inns.
There's so much seafood… from freshly caught lobster to king-size Atlantic salmon… all cooked in unique local recipes or just the way you like it! When the day is through, spend a night tucked away in a cosy seaside inn, a downtown hotel or a luxurious B&B! Where else could you find world-class cities with so much to offer, so close to incredible Natural Wonders!
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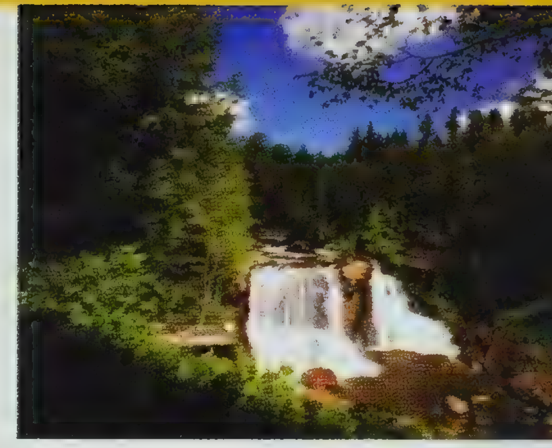
Your dollar is worth MORE in New Brunswick!

WEST VIRGINIA

In Wild and Wonderful West Virginia, nature is always nearby. Hike through rugged backcountry, canoe along meandering rivers, hook some trout in a cold and clear stream, or thrill to some of the best whitewater rafting east of the Colorado.

If birding is your pleasure, visit Monangahela National Forest (304-636-1800), a secluded getaway set in a sprawling 909,000 acres. It is home to 230 species of birds, including warblers, a variety of migratory hawks, and songbirds. Monangahela includes Cranberry Glades, whose unique plants are descended from seeds that took root more than 10,000 years ago. Watoga, West Virginia's largest state park, in the Allegheny highlands, attracts wetland birds such as woodcocks, wood ducks, and waterthrushes.



In Tucker County, Canaan Valley is a beautiful and rare treasure with significant wetlands and northern forest. Canaan's high altitude and moist climate support many unusual and rare plants and animals, including almost 600 plant species and nearly 300 species of mammals, birds, reptiles, amphibians, and fishes.

WITH THOUSANDS OF ACRES OF WELL-KEPT PARKS, FORESTS, AND WILDERNESS AREAS, THE MOUNTAIN STATE IS CHOCK-FULL OF OPPORTUNITIES TO EXPLORE THE OUTDOORS.

West Virginia's varied terrain is criss-crossed with miles of trails. The popular Appalachian Trail becomes part of West Virginia in the Eastern Panhandle, and the Allegheny Trail winds over 300 miles, starting at the Mason-Dixon Line. Explore historic rail trails such as the Greenbrier River and the North Bend, the "trail of tunnels," which give a sense of the B & O Railroad and the towns it once connected.

NORWAY

With its wild, dramatic landscapes, Norway is a land of incomparable beauty. From serene fjords to immense forests, from meandering rivers to bursting waterfalls, the country has a spectacular range of scenery. Lovers of the outdoors can take a walk on a glacier, and on the same day, walk barefoot along a fine sandy beach. Or what about a deep-sea fishing trip in the morning and horseback riding along the fjords in the afternoon? You can ski or go reindeer-sledding in the summer, or for the less active, take a cruise on a transparently clear fjord.

Norway's cosmopolitan cities include its colorful capital, Oslo, framed by fjords and a backdrop of mountains. Over a thousand years old, Oslo has bustling waterfront restaurants, a dynamic nightlife, and fascinating museums where you can explore Norway's cultural history and Viking heritage. Bergen, a charming port city, is the gateway to the country's most impressive fjords. Also not-to-be-missed is Alesund, Norway's art nouveau fishing capital, or Kristiansund, a charming town on three islands.

With many hidden treasures waiting to be explored, a trip to Norway is a once-in-a-lifetime travel adventure.

Photo: Mattias Persson / Norwegian Tourist Board

CAYMAN ISLANDS

THE BEAUTIFUL CAYMAN ISLANDS ARE RENOWNED FOR THEIR SPECTACULAR CORAL REEFS, PRISTINE BEACHES, A GRAND 500 YEARS OF CULTURE AND HISTORY—AND OUTSTANDING BIRDING.

Photos: Top left, Patricia Bradley; Above, Yves-Jacques Rey-Millet

THE CAYMAN ISLANDS ARE HOME TO OVER 200 BIRD SPECIES SUCH AS THE BROWN RED-FOOTED BOOBY (TOP LEFT) AND THE VITELLINE WARBLER (ABOVE).

While travelers are most familiar with Grand Cayman, the "Sister Islands," Cayman Brac and Little Cayman, also entice visitors with their worldly, relaxed Caribbean lifestyle. Both islands are best known for their superb, world-famous diving. But the Sister Islands are also wonderful birding destinations, with over 200 species (80 percent are migrants).

Each island has an interpretative center, a museum, walking and hiking trails, wetland boardwalks, and viewing platforms. Beautiful ceramic signs explain the biodiversity of birds, forests and wetlands, and butterflies and reptiles. And the islands are peaceful and crime-free.

Cayman Brac, whose bluff plateau is about 70 percent tropical forest, has the most resident land birds. Endemic subspecies include Caribbean elaenia, bananaquit, loggerhead kingbird, thick-billed vireo, and vitelline warbler (confined to the Cayman and Swan Islands). Found only on the Brac are red-legged thrush and a subspecies of the rare, threatened Brac parrot, *Amazona leucocephala hesterna* (a second subspecies, *caymanensis*, occurs on Grand Cayman). Counts estimate 400 parrots, with only about 60 breeding pairs. A must for birders is a visit to the National Trust's protected parrot reserve. And don't miss the Brac's colonies of brown boobies and white-tailed tropic birds.

Just five miles west of Cayman Brac lies Little Cayman, with a population under 100. Deserted sandy beaches and mangrove-fringed lagoons make for outstanding wetland birding, with over 70 migrants. There are also resident pied-billed grebe; colonies of tricolored, snowy, and yellow-crowned night-heron and black-necked stilt; and one endemic land bird, the Greater Antillean grackle. The Booby Pond Nature Reserve has the largest red-footed booby colony in the Caribbean—more than 20,000 birds—and a magnificent frigatebird colony. Stop by the viewing platform at Grape Tree Pond, a favored breeding site for a growing population of threatened West Indian whistling-duck. The only West Indian endemic duck, the "whistler" is normally shy, but a robust conservation effort at Great Pond has made it unconcerned with visitors.

In between birding outings, you can take in the Sister Islands' many cultural sites, including historic houses that give a glimpse of eighteenth-century life.

Looking for a special getaway that offers more for your family than just roller coasters? How about considering the island of Cayman Brac in the Cayman Islands? During our exclusive family escape week from July 13-20th, your family can explore island caves on a guided spelunking adventure. Take diving certification classes. Go on bird sightings with an expert guide and see birds found nowhere else in the world. Discover Cayman Brac. And discover something special – your family.

Space for the Cayman Brac Family Escape— July 13th-20th, 2003— is limited, so reserve your family's vacation escape now!

Go to NatureCayman.com for information and reservations, or call 1-866-THE-BRAC.

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CAYMAN ISLANDS

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The *American Queen*

Take a journey back in time when you sail with the Delta Queen Steamboat Company, America's oldest cruise line.

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The *Delta Queen*, America's oldest overnight paddle-wheeler, has been expertly restored. There are no televisions, but there is plenty of Victorian elegance, old-fashioned entertainment, and the impeccable service of a statelier era. On the *Mississippi Queen,* old-time banjos and a calliope belt out favorites from long ago. And on the *American Queen,* you can gaze out the floor-to-ceiling windows of the two-story dining room.

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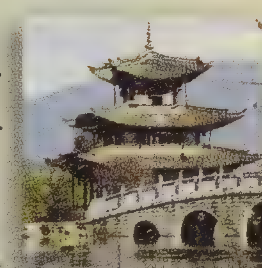

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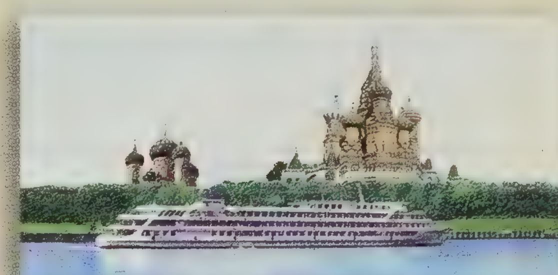

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BIOMECHANICS

Throwing Yourself into It

Were the weights held by Greek long jumpers a help or a hindrance?

By Adam Summers ~ Illustration by Patricia J. Wynne

Jumper holding weights, Greek red-figure cup, Evergides Painter, fifth century B.C.

At the Summer Olympics of 1968, in the dry, thin air of Mexico City, Bob Beamon redefined the limits of human performance. The altitude of the venue had led many sportswriters to speculate that records would fall, and the long-jump record was certainly in jeopardy. Jesse Owens's mark of 26 feet 8.5 inches had finally been surpassed in 1960 after having stood for twenty-five years; in the ensuing eight years it had been pushed eight inches. But no one was expecting what was to come. In the Mexico City long-jump finals, in a transcendent display of physical coordination, Beamon jumped twenty-two inches farther than anyone ever had. At 29 feet 2.5 inches it remains the Olympic record, the oldest one still standing; even now, thirty-five years later, the long-jump world record is just two inches greater.

Given Beamon's achievement, it seems ludicrous to say he could have done even better. But a new study of Olympic long jumping suggests that if he had been carrying a gallon jug of milk in each hand, he might still have the world record today.

Alberto Minetti, a biomechanist at Manchester Metropolitan University in Alsager, England, is fascinated with human locomotion. He has explained why small children like to skip but adults don't, how toddlers toddle, and what a strolling gait would look like on another planet. Now, with his colleague Luca Ardigó, he has turned his attention to the role of ancient Greek sporting equipment. In the process he has unraveled a minor archaeological puzzle.

Records of the eighteenth Greek Olympiad, held on the plain of Olympia in the city-state of Elis in 708 B.C., are preserved as detailed paintings on the sides of vases. Documented in some of the sporting scenes are athletes holding peculiar stone or lead implements called halteres. The function of these implements had never been entirely clear. From the paintings on the vases, archaeologists had gathered that in the standing long jump (not to be confused with the running long jump, for which Beamon is celebrated), the athlete would hold one haltere in each hand. During takeoff, he (the ancient Olympics were not co-ed affairs) would swing them both forward; then, while landing, he would swing

them back behind his body. But were the halteres carried to encumber, and thus handicap, the best athletes? Or were they, somehow, performance enhancers? Minetti and Ardigó, working with mathematical models and measures of jumping performance, have found that the latter is the case.

The distance covered in any jump depends on three factors: the angle and the velocity of the takeoff and the starting point of the jumper's center of mass. Although handheld weights don't increase the jumper's velocity (indeed, intuitively one would think they had the opposite effect) or change the launch angle, they do affect the center of mass.

Consider our depiction of an ancient jumper moving his arms [*see illustration above*]. As the athlete swung his arms forward, his center of mass would move forward and upward be-

fore his feet had even left the ground. In effect, the jumper gained the advantage of leaping from a slightly higher position, set a little past the takeoff line. As the jumper then came in for a landing, he would swing his arms backward. That motion did nothing to change the trajectory of his center of mass, which traced a parabola as the jumper moved through the air. But it did enable the athlete to push his feet farther out in front of his center of mass than he could without the halteres. As long as the extra weight hadn't slowed his takeoff, that push

would have enabled him to go farther, much as if he had swung over a fence and, at just the right moment, pushed off the top rail.

In spite of all the swinging and weight-shifting, the extra weight might still seem an obstacle for a jumper. After all, the kinetic energy of any object—a jumper included—is equal to half its mass multiplied by the square of its velocity. It might seem that adding mass would reduce takeoff velocity, and, that because of the squared velocity, such a trade-off would be far less efficient for the jumper. Yet there is good reason to suppose that takeoff power might actually increase with increasing weight—at least within limits. The more slowly muscles contract, the more force they are able to deliver, which is why heavy weights can only be lifted slowly. Perhaps with some small increase in weight, Minetti and Ardigó reasoned, the added force of the muscle would actually generate more power, leading to an increase in jump distance.

Using a computer model of a jumper, the two investigators determined that adding between eight and fifteen pounds of weight did increase takeoff velocity. Heavier weights than those offset the increase in muscle force, leading to takeoff velocities either equal to or slower than those of an unburdened jumper. The model predicts improvements in jumpers' launch velocities of about 2 percent—an enormous gain in performance at elite levels of competition.

The predictions of computer models are often more compelling than the empirical results with living, breathing (and misbehaving) human beings. But in this case quite the opposite is true. People untrained in long jumping were asked to select a set of randomly weighted halteres, and then to jump while swinging their arms from a platform that measured takeoff forces. Jumpers carrying weights ranging from two to about twenty pounds managed to increase their takeoff power by more than 5 percent. Minetti and Ardigó attributed the improvement over the computer model to the energy-storing effect of the body's elastic tissues: tendons, ligaments, and muscles. Such tissues stretch like rubber bands when loaded. When the jumper takes off, they spring back and return the energy to the jumper.

Such a small increase in power may not seem like much, but even for the untrained jumpers of the experiment, it would add seven inches or so to a ten-foot standing long jump. The last time the standing jump was an Olympic event, at the 1912 games in Stockholm, the three medal-winning jumps were separated by less than four inches; the winner leapt just over eleven feet. Assuming a modern long jumper could master the awkward matter of swinging both hands together during a running start, a similar gain would add about a foot to the distance. Perhaps Mike Powell, the current world-record holder, would be interested in coming out of retirement to try out a well-used set of stone hand weights.

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Jumping youth holding weights, Greek red-figure cup, fifth century B.C.

The Longest Winter

A series of deep freezes descended across the Earth 750 million years ago, each lasting millions of years. The spring that finally took hold may have triggered the present bloom of multicellular life.

By Gabrielle Walker

Look around, take in the intricacies of life on Earth, and then consider this: complex life is a very recent innovation. For billions of years the only earthlings were made of goo. Huddling together in the primordial sludge, they coated the seafloor and inched their way up the shore with the tide; they clustered around steaming hot springs and soaked up rays from the faint young Sun. Dull green or brown, excreting a gloopy glue that bound them into mats, these creatures were little more than bags of soup. Each was just a single cell. Each had mastered the rudiments of how to eat, grow, and reproduce, no more. Each was its own cottage industry in a society that had no interest in collaboration or specialization. The Earth was Slimeworld, just about as simple as life gets.

Then, suddenly, roughly 590 million years ago, something shook the Earth out of its complacency. That event—whatever it was—gave rise to the beginnings of eyes, teeth, legs, wings, feathers, hair, and brains. For life, it was the Industrial Revolution. Forget the old cottage industries where each single cell had to perform all the tasks of living. Now factories with specialized departments could thrive. From that moment, simple slime yielded its preeminence to the complex creations that heaved their way out of the sludge and started life's long march toward modernity. Whatever triggered that chain of events was ultimately responsible for the existence of you and everyone you've ever known.

Paul F. Hoffman, a geologist at Harvard University, thinks the culprit was something truly extraordinary—the biggest climate catastrophe the Earth has ever known. That idea has been lurking in the scientific shadows for nearly sixty years, but Hoffman has now brought it firmly into the limelight. Marshaling evidence in rocks from Australia and Namibia to Russia and Newfoundland, Hoffman contends that life's richness, diversity, and sheer overwhelming complexity arose from a prodigious disaster known as "snowball Earth."

For a few thousand years, ice crept from its strongholds at the Poles. But when the ice reached the Tropics, its slow creep became a sprint.

Some 750 million years ago, says Hoffman, ice began to creep southward and northward from its strongholds at the North and South Poles. Individual crystals of ice first appeared in the sea like tiny floating snowflakes. They were smashed together by wind and waves, their fragile arms broken and their debris turning the water slick. The surface thickened and froze. In some places, the ice congealed into large pancakes, with raised edges like those of giant lily pads where they bumped and crashed against one another.

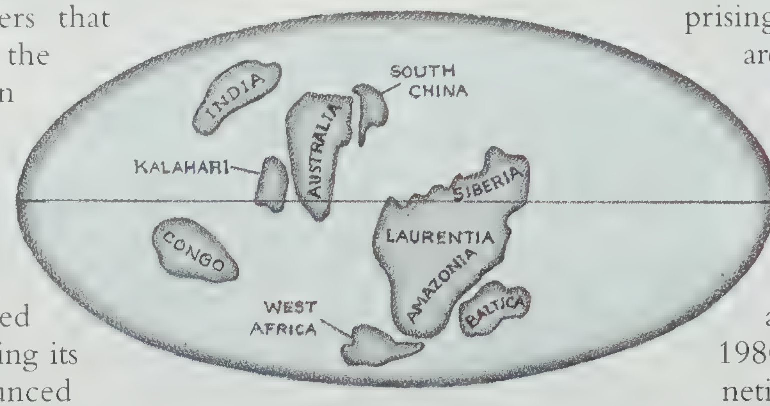
For perhaps a few thousand years, the ice stole unheeded toward the equator, while most of the Earth's life-forms bathed in the warmth of the shallow, equatorial seas. Geysers blew. The Sun shone. Rain fell. There was no hint of the devastation to come.

But when the ice reached the Tropics, its slow creep became a sprint. In a matter of decades, ice engulfed the tropical oceans. It spread out from shallow bays and grew a skin, then a carapace, over the oceans. It clung to the beaches and scraped against the microbial mats coating the

Andy Goldsworthy, *Thin ice, made over two days, welded with water from dripping ice, hollow inside, Scaur Water, Dumfriesshire, 10–11 January 1987*

seafloor. In some places the shell of ice stayed thin enough to crack and seal again. In others it was thousands of feet thick.

At first the land itself remained bare. Then ice began to accumulate there, too, condensing out of the thin air of mountain ranges, creating great frozen rivers that flowed down to fill the surrounding valleys. In the end, the whiteout was complete. Earth's surface looked like the frigid wasteland of Mars, or one of Jupiter's ice-covered moons. Instead of adding its warmth, sunlight bounced off the bright surface and was dazzled back into space. The average temperature plummeted to −40 degrees Fahrenheit. Clouds by and large disappeared, except perhaps for minute ice crystals high in the atmosphere, which scattered sunsets into blue and green rimmed with vibrant pink. No rain fell, and little snow. Every day brought silent, unremitting cold.



A proposed distribution of Earth's landmasses 750 million years ago (Laurentia would become part of North America, Baltica part of present-day Europe). Geologists now speculate that this continental arrangement may have created conditions that gave rise to "snowball Earth."

Hoffman's snowball wasn't just another brief cold blip in an otherwise fairly comfortable world, like the ice ages of the more recent geological past. Instead, it was the coldest, most dramatic, most severe shock the planet has ever undergone. The entire world was coated with a layer of ice nearly a mile thick, and for perhaps 100,000 successive centuries the Earth was a frozen white ball, desolate and all but lifeless.

There may have been as many as four snowball episodes until 590 million years ago, when the last one melted. Some microorganisms survived the deep freeze, of course—if they hadn't, they wouldn't still be around today. Maybe they huddled around undersea volcanoes or near hot springs, or found fissures and cracks in the sea ice where the Sun's rays could slip through. But for many, perhaps most of them, the snowball was disastrous.

Evidence for the snowball is written in the only surviving record from the late Precambrian: rocks. All over the world, on every single continent, rock outcrops contain mad jumbles of pebbles and stones of every shape, size, color, and provenance. They are scratched and scarred from having been bulldozed out of their home territory and dragged hundreds of miles across the landscape. And lodged in siltstone outcrops that used to form the Precambrian seafloor are occasional giant boulders, dropped by icebergs that were once passing overhead. Only one agent could have transported so many kinds of rock such long distances: glacial ice.

Hoffman was far from the first person to imagine an ice-encased world—which isn't surprising, since the "ice rocks" are ubiquitous. Half a century earlier an English geologist named Walter Brian Harland had begun to develop the outlines of a "great infra-Cambrian ice age." And in the late 1980s, by examining magnetic iron particles in Australian ice rocks, Joseph L. Kirschvink, a geologist at Caltech, had shown that ice had reached the equator in Precambrian times. Even so, few geologists believed the entire Earth could have frozen over. Snow and ice reflect sunlight much more effectively than rocks. A shiny white icebound Earth ought to send the Sun's rays bouncing back into space, and if the planet ever got into such a state—so the reasoning went—it should never be able to get out of it.

But in 1992 Kirschvink presented a brilliant solution to that conundrum. The snowball, he suggested, was melted by volcanoes. Then as now, volcanoes studded the Earth, periodically spilling out heat, gas, and molten rock. Whether beneath the sea or on land, they were perfectly happy to erupt under ice—as they do today in Iceland [*see "The Ice Above, the Fire Below," by Robert S. White, with photographs by Ragnar Th. Sigurdsson, June 2002*]. And one of the main gases to come from the heart of a volcano is carbon dioxide, CO_2, the gas that threatens us all with global warming. Carbon dioxide lets sunlight in but prevents the Earth's body heat from escaping, and so provides an effective way of warming up a planet. Each volcanic eruption, Kirschvink realized, would pour a little more CO_2 into the sky, eventually turning the air into a thick blanket. And after millions of years of frigid stasis, the ice would finally succumb, melting within perhaps just a few centuries.

The aftermath of the melting would have been hell on Earth. Dante, says Kirschvink, would have been proud of it. To lock the CO_2 back up in the rocks and clear off the blanket would have taken tens of thousands of years. In the meantime, average annual temperatures soared to 100 degrees F

or higher. Intense hyperhurricanes brought floods of acid rain. The Earth had leapt from the freezer into the fire.

Although Kirschvink's inferno was a stirring idea, he didn't pursue it. Before moving on to other things, however, he not only invented the term "snowball Earth" but also mentioned his ideas to Paul Hoffman. A few years later the spark ignited.

In the mid-1990s Hoffman was working among Precambrian ice rocks in Namibia and becoming increasingly baffled by a mysterious layer of carbonate rock immediately on top of them. This "cap" of carbonate bore no pebbly interlopers, no boulders, no signs of ice at all. And carbonate rocks form at the bottom of balmy seas, so finding carbonates right above signs of ice was bizarre—like seeing palm trees in Antarctica. What's more, the carbonates showed up wherever the ice rocks were deposited, on every single continent. And that is peculiar, because one of the first lessons every geologist learns is that the Earth is emphatically not one big layer cake. Individual regions end up layered with quite different kinds of rock. You simply aren't supposed to get single events that blanket the entire planet with the same kind of rock. Period. Except that on every continent, ice rocks are capped by carbonates.

So how could an icehouse turn into a hothouse? The answer came from Hoffman's colleague Daniel P. Schrag, a geochemist also at Harvard. Schrag reasoned that the cap carbonates were a direct consequence of the snowball and its aftermath. The way Schrag envisioned it, the acid that rained onto the ground in torrents after the snowball ended fell onto a thick layer of dust, left behind by millions of years

Lynn Davis, *Iceberg 30, Disko Bay, Greenland, 2000*

of grinding by the glaciers. In the post-snowball world, that combination of ground-up rock and acid rain was a chemical factory waiting to happen. (Think how much faster sugar dissolves when it's not bound up in a lump.)

Rock dust and acid met, mated, and were swept off into the sea. They set the waters fizzing and foaming, creating a Coca-Cola ocean. Oceans frothed and bubbled with dissolved CO_2; rocks dissolved like baking powder. All around the world, the post-snowball ocean turned milky with flakes of white. They poured down onto every inch of the ocean floor. From the chemistry of acid rain and rock dust had come a massive outpouring of carbonate, blanketing the entire planet. The flakes squeezed together, hardened, and turned back into rock. They became the cap carbonates.

Hoffman and Schrag put their ideas together with Kirschvink's and published the amalgam in the journal *Science* in August 1998. That fall Hoffman went from one institution to another, purveying the good news in impassioned lectures. He had never, he said repeatedly, been so convinced that something was right.

But some in his audience were disturbed by the sheer extremity of the snowball vision. To buy into the snowball, you had to think of our home planet acting like some eerily alien world. You had to imagine oceans freezing over completely, even at the equator; an ice age that spanned 150 million years; a planet that plunged from the coldest temperatures it had ever undergone into an intense hothouse within a few centuries; CO_2 levels hundreds of times higher than have ever been seen in the geological record; and rates of rock weathering like nothing on Earth today. How could anyone accept a theory that was so far out of the box?

In the past half decade, plenty of adversaries have attacked the snowball theory, and Hoffman has had to answer their objections. Yet so far, the theory has survived every challenge with its core intact. And Hoffman's proselytizing has brought about a sea change in scientific attitudes. Virtually everyone now agrees that the period from about 750 million until 590 million years ago was a time of extraordinary ice, cold, and catastrophe. Even critics who think the tropics had at least some remaining open water—a scenario appropriately called "slushball Earth"—admit that ice went almost all the way around.

While Hoffman continues to bolster his geological case, he has had to leave the biological implications of the snowball theory to the work of other specialists. How, for instance, did the earlier life-forms survive the deadly ice? And could the snowball have provided the creative spark for the new, complex life that followed?

To answer the first question, you need to think about heat. Any hot spring or volcano on a shallow enough ocean floor would have created at least a small hole in the ice above it. So there would have been at least a few puddles and cracks in which living things could have grabbed their chance to make and store food, as they do in Antarctica today. And according to Douglas H. Erwin, a conservation modeler and the interim head of the Smithsonian's National Museum of Natural History, all you would have needed to get virtually all the extant species through the snowball epoch was about a thousand

Norbert Wu, *Sea Ice Lead, McMurdo Sound, Antarctica*

havens of open water, with about a thousand individuals in each. What's more, because snowball-era creatures weren't exactly gargantuan, each haven could have been no wider than a dinner plate.

But the second question is trickier. Until recently, most biologists had assumed that complex, multicellular life-forms arose about 545 million years ago, during an event called the Cambrian explosion. But that event couldn't possibly have been triggered by Hoffman's snowballs. They ended around 590 million years ago, and 45 million years is far too long to sit around with a lighted fuse waiting for the bang. In fact, fame has come to Cambrian creatures mainly because they invented skeletons, scales, shells, spines—in short, all the various bodily supports that stick around long enough after death to turn into clear, unambiguous fossils. But they needn't have been the first complex animals, any more than papyrus or the printing press marked the beginning of language. Complex, multicellular life-forms could easily have been around for millions of years before the Cambrian, and just not left such a clear record of themselves in the rocks.

If Hoffman is right, if the snowball truly triggered the invention of multicellular life, the world's first complex creations must have appeared shortly after the ice receded. The question is, did they?

One way to answer the question is to supplement fossil hunting with a more oblique approach: the molecular clock. The genetic material inside every living cell carries information about its ancestry. But DNA changes slightly with each generation, with each tick of the genetic clock. If you measure how much DNA has changed from one species to another, and if you know how fast the clock was ticking, you can track evolution backward even without the help of fossils.

Most molecular clocks have indicated that complex animals emerged long before the snowball, too long ago for it to have triggered their appearance. Different clocks, however, have also yielded radically different dates: some said biological complexity began 800 million years ago; others said more than a billion. That inconsistency frustrated Kevin J. Peterson, a biologist at Dartmouth College in Hanover, New Hampshire. Determined to prove once and for all that the beginnings of complexity had nothing to do with the snowball, he decided to make the most accurate molecular clock he possibly could.

Peterson chose echinoderms, a family of creatures that includes urchins and sea stars. Working backward, checking each result against the substantial number of well-dated available fossils in that family (until he ran out of fossils), he finally had his answer. He was stunned. The last common ancestor of all complex animals lived sometime around 700 million years ago. In other words, the appearance of that ancestor coincided almost exactly with the end of the first icehouse episode of snowball Earth.

Recall that Hoffman thinks he is dealing with a

series of events, not just one. Perhaps complex animals were triggered by the first freeze-over and then survived the remaining episodes of ice. It's also possible that despite Peterson's care, his clock overestimates the age of complex animals; some biologists think that genetic changes happened more quickly in the past, and that all molecular clocks yield older times than they should.

If an icebound Earth really did trigger complexity, encouraging life to diversify and experiment, how could it have done so? New species often arise when a single population of creatures becomes isolated from its fellows for a long time, perhaps a million years or so. Or perhaps the ice opened up a niche for complexity by wiping large areas of the planet clean of life. Until the enveloping mats of slime were kept from hogging all the resources, there might have been no way to innovate.

The most popular idea about how to trigger complexity, however, is to shock the system with the planet. Now Schrag has taken that idea a few steps further. When continents spread out to the far north and south, they act as a brake on the spread of the polar ice caps. White ice reflects sunlight, which causes cooling, and that breeds more ice. Rocks, by contrast, normally prevent the Earth from overheating: in the chemical reaction known as weathering, rock and water combine with atmospheric CO_2, thereby removing one of the major greenhouse gases that volcanoes pump out. But if polar ice starts to spread, the rocks of high-latitude continents no longer soak up CO_2. Instead the gas stays in the atmosphere to do its greenhouse thing, warming up the Earth and melting the excess ice. That's what happens in the reassuring continental arrangement we have today.

Now imagine what would happen if all the continents were arranged in a band around the equator. The polar ice caps could spread with impunity. By the time ice reached the equatorial continents, a

When the continents bunch together near the equator, an alternating icehouse-hothouse cycle may ensue—until the continents move on.

oxygen—the agent that "burns" food and enables animals to develop large and complicated bodies. For millions of snowball years, when life would have been restricted to a few small refuges, unused nutrients would have built up in the sea, making it into a tasty chemical soup. As soon as the period of ice was over, the white planet would have become green. Massive colonies of bacteria and algae would have soaked up sunlight, made food, and belched out oxygen as a waste product. That sudden pulse of oxygen may have been just what complex life was waiting for.

One question remains outstanding: Why did the snowball ever happen at all? The answer may lie in a peculiar alignment of the continents. As the world's tectonic plates drift over its surface, the continents sometimes scatter and sometimes bunch together. On rare occasions they arrange themselves in a band around the equator—and there's reasonably good data suggesting that might have been the case during Hoffman's snowball.

More than a decade ago Kirschvink suggested that if all the available landmasses were collected in the tropics, they would reflect more of the incoming sunlight than seawater does, and so help cool snowball would be unstoppable. And as long as the continents stayed in the tropics, the alternating icehouse-hothouse cycle would continue—until eventually the continents moved on.

The good news is that another snowball is unlikely to be imminent. Reassembling the continents into a band around the equator will take at least a few hundred million years. But the bad news—at least if the threat is a snowball—is that the Earth has come a long way since the simple days of Slimeworld, and life is now a complex web of interdependent creatures. If another snowball should ever engulf the Earth, many—perhaps most—of those creatures would perish.

Perhaps our descendants will be so unimaginably advanced that they will be able to prevent a snowball. But the Earth is a powerful and stubborn force. It limits our resources, and its geological will is extremely hard to check.

If distant descendants of the human lineage cannot stop another snowball, could they weather it? That, too, is hard to imagine. Getting a few simple marine creatures through the ice is one thing, but the complex creatures that inhabit our planet today present a much bigger challenge. Antarctica is the

Lynn Davis, *Iceberg 34, Disko Bay, Greenland*, 2000

most hostile place on Earth. Unless you take your own life-support system of food, fuel, and shelter along with you, you die. And on a snowball planet, Antarctica takes over everywhere in the world. For any truly complex creatures, the result would surely be disastrous. Norse mythology has a word for it: after the catastrophe of *Fimbulwinter* comes *Ragnarok,* the end of the world.

But a new snowball would not be the end for all life on Earth, any more than the earlier ones were. Our planet is, after all, a master of invention. Through geologic time, the Earth has constantly taken on remarkable new identities. One mountain range rises; another falls. Oceans open here and close there. Change doesn't alarm the Earth; it is a fundamental part of its nature. We human beings, and the other creatures that share our slice of geologic time, are the fragile ones. □

This article has been adapted from Snowball Earth: The Story of the Great Global Catastrophe That Spawned Life As We Know It, *by Gabrielle Walker, which is being published this month by Crown.*

Date with Extinction

For a thousand years before people settled in New Zealand, a small alien predator may have been undermining the islands' seabird populations.

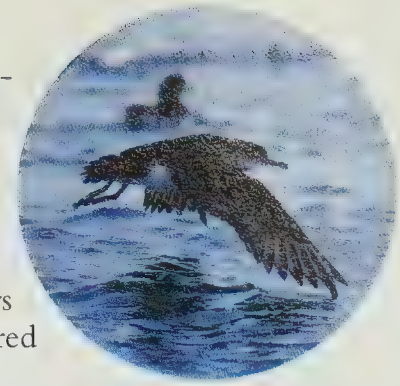
By Laura Sessions

Hutton's shearwater, a species of petrel, is still abundant near the shores of New Zealand's South Island. Here the birds rest on the sea within sight of their nesting area, about 5,000 feet up in the Seaward Kaikoura Range.

Our yellow Zodiac bobbed across the choppy sea and made its way slowly through the clouds of seabirds that wheeled and soared around us. Albatross, cape pigeons, diving petrels, mollymawks, mottled petrels, and sooty shearwaters all took their turns skimming our bow wave for fish. In the distance my boat mates and I could see the final stop on our sub-Antarctic tour: the Snares Islands, about 130 miles south of New Zealand's South Island. The chorus of screeching birds drowned out our rumbling boat motor, and even from several miles away we could smell the acrid white guano that coats much of the Snares's rocky coasts. During the summer breeding season the Snares, whose entire area totals not much more than one and a quarter square miles, are home to more than 6 million seabirds—as many as nest along the coasts of Great Britain and Ireland combined.

Today in the New Zealand archipelago, such dense seabird colonies persist only on small offshore islands, but at one time much of the coastline of the North and South Islands (by far New Zealand's two largest islands, commonly called the mainland) would have been equally pungent and raucous. New Zealand once supported one of the most diverse seabird faunas in the world; the country was particularly rich in species of petrels. Nowadays those populations have crashed, and many species have been extirpated on the mainland. One can only imagine what it must have been like for ancient Polynesian seafarers reaching the shores of uninhabited New Zealand. The archipelago, no doubt a welcome sight after months of arduous ocean sailing in a double-hulled canoe, would also have presented a far different scene from that of most of New Zealand today.

But did these colonizers encounter a truly pristine environment? It would be easy to "round up the usual suspects" and blame the loss of so many species from the mainland on the encroachments of civilization. But in reality, the early Polynesian settlers were not responsible for the destruction of many of the seabird populations. Even before people settled this southern land, other visitors may have already irrevocably altered the New Zealand environment.



A Hutton's shearwater skims the ocean surface, a habit that gives shearwaters their name.

Those earlier arrivals on the New Zealand mainland were Pacific rats *(Rattus exulans)*, or *kiore*, as they are called in the Maori language. It has been known for almost a decade that these small stowaways helped drive some of the native bird species from the mainland, or, in some cases, to outright extinction. According to the standard account of the invasion, the rats arrived in New Zealand between 800 and 1,000 years ago, in the canoes of the first Polynesian settlers. But in 1996, Richard Holdaway, an independent extinction biologist, presented evidence that the rodents first made landfall perhaps a thousand years earlier. That date has called into question the entire sequence of prehistoric events that shaped New Zealand—and, not surprisingly, has fueled much debate in New Zealand about the strength and validity of Holdaway's evidence.

But even more, Holdaway has hypothesized that a rat-generated crash in island bird populations could have led to "a cascade of damage" and even to a change in the nearshore oceanic food web: seabird colonies generate a prodigious quantity of guano, which can form a kind of organic bridge between sea and shore, enriching soil and promoting plant growth. If the seabird populations crashed, Holdaway argues, so did this bridge. The islands would have lost a major source of nutrients. If Holdaway is right, the rats had accidentally landed on a choke point of the ecosystem, causing a ripple effect that went far beyond the destruction of seabirds.

Thanks to their remoteness—New Zealand lies 1,200 miles east of its nearest neighbor, Australia—the North and South Islands faced the onslaught of invaders considerably later than did many other islands around the globe. But just as they have on Hawaii and Guam, alien species that were suddenly introduced onto the islands have had devastating effects. New Zealand birds were particularly at risk, because they had evolved for millennia in the absence of mammalian predators (indeed, the only land mammals of prehistoric New Zealand were three species of ground-feeding bats). Many of the native birds were flightless and seminocturnal, mak-

ing them easy prey for the rats and the eleven other introduced species of predatory mammals that eventually prospered in the archipelago. Even seabirds were vulnerable; though they can spend months of each year at sea, many of them nest in ground burrows and are helpless against terrestrial threats.

As an ecologist and environmental writer, one of my main interests is to understand the damage that relatively recent introductions—from stoats to wasps to possums—have wreaked on native plants and animals. Often enough, I have discovered, even one such invader can set in motion a spiral of ill effects [*see "A Floral Twist of Fate," September 2000, and "New Zealand Sweet Stakes," May 2001*]. It was through those interests that I first met Holdaway, and became acquainted with his work, in 2001. Holdaway not only shares my concerns about the current state of New Zealand's ecosystems; he also adds perspective by looking to the past. He hopes to document the species of prehistoric New Zealand, how its ecosystems worked, and what they can say about the islands today.

A pair of Pacific rats feed on fruit. But given the chance, these mouselike rats readily devour small adult birds, chicks, and eggs. Evidence suggests that Pacific rats were the first mammalian predators introduced to New Zealand.

From 1991 until 1995 Holdaway took part in a collaborative study to examine fossils for signs that early Polynesian settlement had led to changes in animal populations and the mix of animal species. When rat bones were discovered at some of the fossil sites, he decided to test the assumption that the rats had arrived in New Zealand with the people who settled in the islands about 800 years ago. (Archaeologists have established the dates of those settlements on independent grounds.)

Holdaway measured the ages of the fossil rat bones discovered at non-archaeological sites, that is, sites without evidence of human settlement, with accelerator mass spectrometry (AMS)—a relatively new and particularly sensitive method of radiocarbon dating. To his astonishment, the AMS readings showed that some of the bones were as old as 2,000 years. That may sound recent by the standards of North American or European archaeology, but it is ancient history for New Zealand, the last large habitable landmass to be settled by people. The early date suggested that rats had not only occupied New Zealand before any other introduced land mammal, but that they had appeared on the scene more than a millennium before any human settlers.

How firm are Holdaway's findings? How likely are they to stand up to further scientific scrutiny? The late astronomer Carl Sagan once remarked that "extraordinary claims require extraordinary evidence." The implications of Holdaway's theory of early rat arrival are far-reaching, both for ecology and for the protohistory of Polynesian migrations. And sure enough, his findings have been hotly contested by some archaeologists, who have questioned the accuracy of his radiocarbon dates.

Atholl Anderson, an archaeologist at the Australian National University in Canberra, argues vigorously that dates earlier than 800 years ago, as determined by AMS measurement, can be explained by contamination of bones in the deposits. Recently, however, Holdaway published the results of a comparison between radiocarbon dating and a second technique, known as optical dating, carried out by geochronologist Bert Roberts of the University of Wollongong in Australia. Optical dating determines when the quartz grains in the sediments containing the fossilized bones were last exposed to sunlight. The technique made it possible to estimate how long the sediments and the rat bones had been buried. The results of those tests confirmed the radiocarbon chronology for the Pacific rat fossils.

Archaeologists also point to the lack of evidence for human colonization of New Zealand before about 800 years ago. Known for their intrepid voyages throughout the Pacific, the people who first permanently settled New Zealand were eastern Polynesians in language and culture, and they were to become the direct ancestors of the Maori people. Holdaway believes that any population of more than about fifty people occupying New Zealand for any length of time would have left clues to their presence, such as bones of large flight-

less birds killed for food, or the remains of cleared forests—as the first settlers did. Yet no evidence for settlements more than 800 years old has ever come to light.

So if the colonizers didn't bring the rats, how could the animals have come to New Zealand? Pacific rats originated in southeastern Asia. Could they have made the trip on their own? The answer is surely no. The animals are reluctant swimmers, unable to cross water barriers more than 200 yards wide, even in the tropics. And it is unlikely that they rafted on vegetation to New Zealand from some far-off South Pacific isle. In spite of their relatively long tenure in the North and South Islands, they did not reach some of the offshore islands of New Zealand until quite recently.

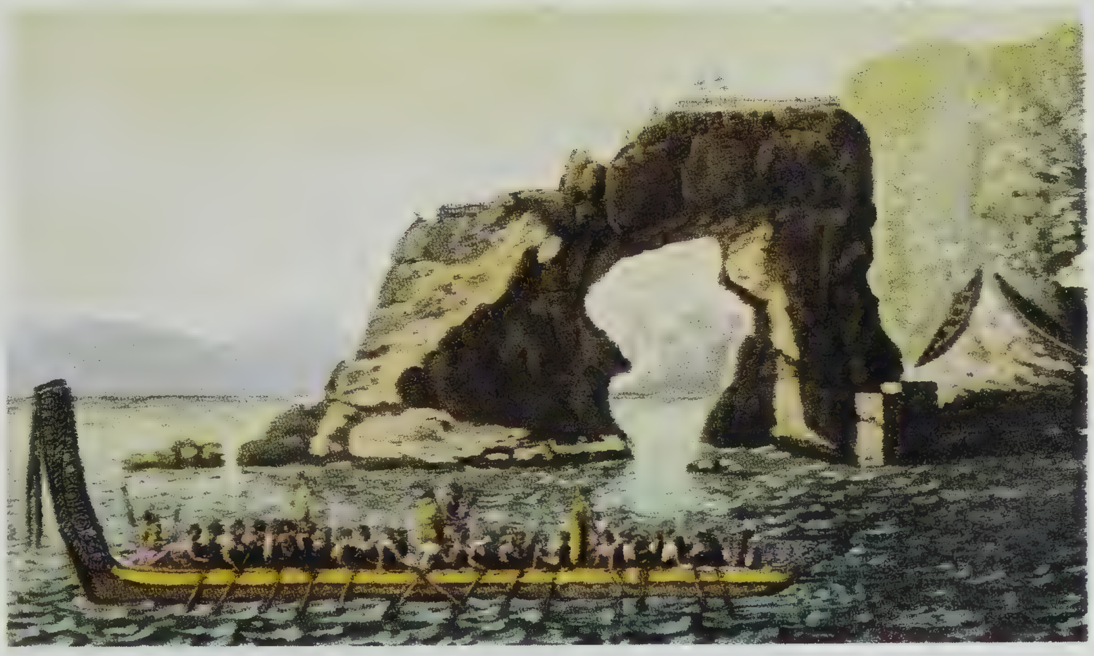
Skeleton of the neck and head of a moa, a long-necked flightless bird that grew as tall as six and a half feet. Native to the islands of New Zealand, moas were rapidly hunted to extinction by the Maori. (Photograph by Rosamond Purcell)

Holdaway agrees with that scientific consensus: people brought rats to New Zealand. In fact, the Polynesians are known to have sometimes transported Pacific rats—perhaps at times for food—throughout the vast Pacific triangle, from Hawaii to Easter Island to New Zealand. But Holdaway thinks the people who brought the rats to New Zealand were earlier seafarers known as Lapita, who were probably the ancestors of the Polynesians. The Lapita left no archaeological evidence of their presence in New Zealand, Holdaway argues, simply because their visits to such southern latitudes were so transient. They may have touched on New Zealand shores intermittently for centuries before they, or other early Polynesians, decided to stay. And for rats to have arrived, become feral, and established themselves in the new habitat, they need not have "jumped ship" or been purposefully introduced in great numbers. Pacific rats, after all, are rodents, and so they are prolific reproducers; arriving at the right time of year, one pregnant rat could eventually have populated an entire island.

The idea that intermittent visitors carried rats to the islands several times is borne out by a study of the mitochondrial DNA of Pacific rats by Lisa Matisoo-Smith, an anthropologist at Auckland University in Auckland, New Zealand. Matisoo-Smith compared genetic sequences in Pacific rats from New Zealand with the same sequences in rats of the same species from other Pacific islands. Random mutations in mitochondrial DNA accumulate at a slow but relatively constant rate.

Matisoo-Smith reasoned that the mutations could serve as a clock for determining the arrival dates of rats on various islands across the Pacific. Assuming the rats arrived with early Polynesians (or perhaps with the Lapita), the rodents' mitochondrial DNA could serve as an independent record of prehistoric human migrations. Her data show that the rats living in New Zealand today carry genetic heritages from various lineages of *R. exulans,* suggesting that they were introduced to New Zealand more than once, from various geographic sources.

Ecologists have only recently come to recognize that the rodents could have fundamentally altered



Maori seafarers power a war canoe in inshore waters, as depicted in this engraving by Paulo Fumagalli and his assistants. The Maori, a Polynesian people, were the first group to establish permanent settlements in New Zealand. Their oceangoing vessels, unlike their war canoes, were double-hulled and had triangular sails.

A kakapo, New Zealand's ground parrot, uses its stubby wings for display but not for flight. Adults are too large for Pacific rats to threaten directly, but their eggs are a manageable mouthful.

New Zealand's ecosystems. Until a decade ago, most biologists thought that Pacific rats, unlike Norway rats *(R. norvegicus)* and black, or ship, rats *(R. rattus)*, were vegetarians. Pacific rats do feed frequently on plants and insects, but they are also avid meat eaters when the opportunity arises. Moreover, because rats are nocturnal, few people had actually seen them in the act of predation until infrared video captured them at their gruesome tasks.

By indirectly disrupting the flow of nutrients from the sea, the small Pacific rat may have altered island wildlife throughout the Pacific.

But by now biologists have observed them attacking adult saddlebacks (a native songbird whose numbers are dwindling) and devouring eggs of the little shearwater (a native petrel). Petrel chicks are sometimes skinned alive and their eyes eaten out. And Pacific rats are voracious. In New Zealand they weigh in at less than half a pound but can devour any prey as large as they are and eat eggs two-and-a-half inches long. They can even threaten the eggs of such large birds as the kakapo, the heaviest parrot in the world and now one of the rarest.

The Polynesians themselves are usually blamed for irrevocably changing the landscape of a pristine New Zealand. Indeed, Holdaway and his colleagues have found evidence that within a hundred years or so of their arrival, Polynesian settlers had hunted the giant flightless birds known as moas to extinction. But if Holdaway's work is on the mark, New Zealand was far from pristine when the Polynesians came to stay. Rats that arrived 1,000 years before any permanent human occupation would have had more than twice as long as people had to alter their adopted ecosystem.

Although Polynesians might occasionally have killed and eaten lizards and the small flightless wrens that were once widespread throughout the islands, they would hardly have hunted such smaller prey to extinction. The Pacific rat was the only small feral mammalian predator in New Zealand before the European era began with the arrival of Captain James Cook in 1769. (Archaeologists think that Polynesian dogs, also introduced by Polynesian settlers and kept for food, had little impact on native species.) The blame for those extinctions clearly rests with the rat.

When Pacific rats arrived in New Zealand, they found themselves in a land of plenty. Millions of seabirds nested in ground burrows. Other birds, such as the flightless wrens, emerged at dusk to forage, the rats' favorite time to hunt. The rats simply did what any hunter would do. Their victims were well-adapted to avoiding birds of prey, which had always occupied the islands. But predatory birds attack from above, relying on their excellent vision to sight prey during daylight. The rats hunted by night, on the ground, with their keen sense of smell.

A series of inadvertent natural experiments, involving the mix of people, rats, and wildlife on some of New Zealand's offshore islands, suggests in even greater detail how rats may have affected native fauna over time. For example, on offshore islands such as Aorangi and Stephens—which became home to Polynesians but never to Pacific rats—petrels, other small birds, invertebrates, frogs, and lizards still abound. Those species have largely disappeared from islands inhabited for long periods by Pacific rats.

It is the petrels, though, that most dramatically illustrate the magnitude of the damage that rats prob-

ably inflicted in New Zealand. Thirteen species of petrel once bred on the South Island. Today only six still breed there, and only one, Hutton's shearwater, remains on the island in great numbers. The seven extirpated species certainly disappeared before the Europeans arrived and may have been gone even before the Polynesians settled in New Zealand.

The petrel species that became extinct were precisely the ones whose size and habitat made them most accessible to the Pacific rats. Petrel species that were too big a mouthful for rats persisted on the mainland, even in lowlands, where rats were common. In contrast, the smaller petrel species all disappeared, even where their breeding habitats remained intact. Scarlett's shearwater, for instance, disappeared from the west coast of the South Island, even though the area retains some of the largest tracts of relatively undisturbed forest in the country. The only small petrel species that survived were the ones that nested on rat-free offshore islands or in cold mountainous regions, inhospitable to subtropical rats. Many of those refuges were later invaded by other, even feistier rat species and by stoats introduced by Europeans.

If rats were responsible for killing off petrels and other native species, what additional effects might their depredations have had? By eliminating huge colonies of seabirds, for instance, Pacific rats could have generated ecological damage far beyond the extinction of particular species.

Holdaway has drawn particular attention to the amount of organic waste once generated by the seabird colonies—mainly guano, but also lost eggs, dead birds, spilled food, and molted feathers. That waste would have constituted a bonanza of nutrients that flowed continuously from the sea to the land. (Miners on other oceanic islets, such as Nauru and Christmas Island, have come across guano-derived phosphate rock deposits as thick as seventy-five feet.)

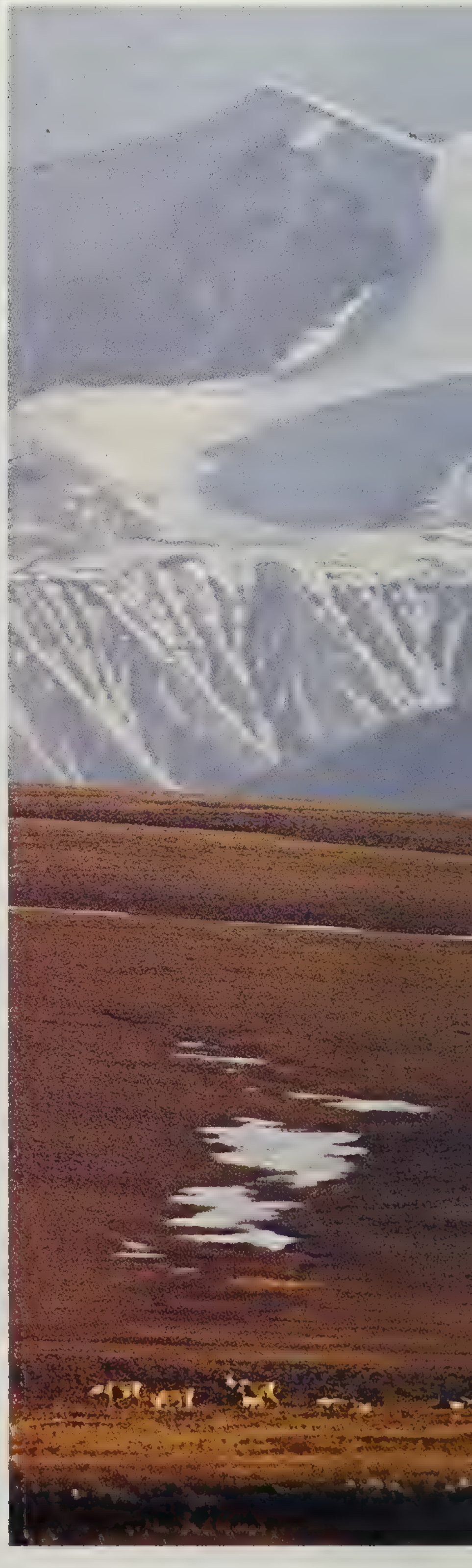
The massive wastes of the seabird colonies on the mainland would have added phosphorus, nitrogen, and carbon to relatively nutrient-poor soils, and lowered the pH of the soil. The birds would also have aerated the soil as they burrowed to shape their nests. The nutrients would have fostered the growth of plants that sustained invertebrates, lizards, birds, bats, and other herbivores. Take the case of Hutton's shearwater. Holdaway estimates that a remnant colony of these birds on the South Island still supplies more than 1,000 pounds of guano per acre in each breeding season. Extrapolating from that estimate, he maintains that before the appearance of the rats, seabird colonies could have supplied two million tons of fertilizer a year.

The possible implications of the loss of such a nutrient flow are astonishing. Pacific rats have spread to hundreds of islands and have eliminated hundreds of seabird populations. If those changes have equally disrupted hundreds of food webs, it could be that these small rodents have altered island wildlife across the entire Pacific. Holdaway's next step is to collaborate with investigators from a variety of disciplines to examine the possible connections between petrel disappearances and changes in those food webs. The Pacific rat may be the only mammal in the world, besides our own species, that has fundamentally altered an ecosystem on a continental scale. □

The Westland petrel, big and mean enough to fend off even large Norway and black rats, is one of the few petrel species that still breeds on the New Zealand "mainland," and whose numbers are on the rise.

Capitate lousewort, temporarily shrouded by a summer snowfall

Photographs by Subhankar Banerjee



Here the summer sun lingers above the horizon from mid-May until mid-August. Here the sky of the long winter night dances with the luminous curtains of the aurora borealis. The setting is the Arctic National Wildlife Refuge, in the northeastern corner of Alaska. Its 30,000 square miles of wildlands straddle the Continental Divide, including the four highest peaks and most of the glaciers in the Brooks Range. Waterways that flow northward cross the tundra of the coastal plain and empty into the Beaufort Sea; waters flowing southward pass through forests of spruce and birch to join the mighty Yukon River or the Porcupine River, one of the Yukon's tributaries.

In May and early June the coastal plain serves as the principal calving ground for the Porcupine herd of caribou. Musk oxen give birth on the plain a bit earlier, from mid-April until mid-May. In the past few years, apparently as a result of global warming, the coastal plain has had more snow than usual and, as a consequence, a later spring thaw. Driven to the foothills to find forage, the musk oxen are more often giving birth there, even though that makes them and their young more vulnerable to grizzly bears. The net result is that their numbers are in decline.

Altogether the refuge is home to thirty-six species of land mammals and nine marine mammals that frequent its coast. About seventy species of birds nest on the coastal plain; another sixty-five make their annual pilgrimages from lands as distant as South America and Southeast Asia, just to feed on the clouds of early summer insects.

The refuge was created in 1980, enlarging a national wildlife range established in 1960. Nearly 14,000 square miles are designated as wilderness and are governed by the 1964 Wilderness Act. Mining and timber cutting are forbidden, and recreational equipment is circumscribed. But the coastal plain, despite its pivotal ecological role, is not classified as a wilderness area.

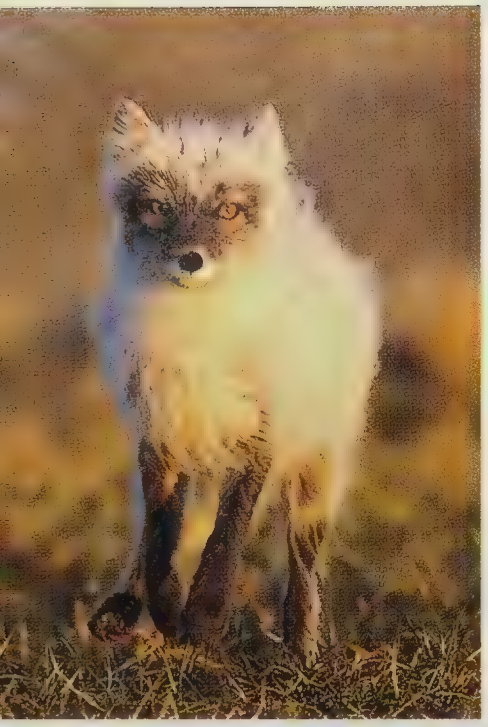
Owned by the citizens of the United States, the Arctic National Wildlife Refuge is now managed by the U.S. Fish and Wildlife Service (www.r7.fws.gov/nwr/arctic/arctic.html). More than 300 archaeological sites, however, attest to the priority of an indigenous human presence. Exploiting the tundra and the sea are Inupiat Eskimos, traditional hunters of bowhead whales, while in the interior forests live the Gwich'in Athabascan Indians, whose fate and culture have long been joined with the herds of caribou. Inhabiting settlements on the periphery of the refuge, these people remain among its best-informed guides.

—Vittorio Maestro

Arctic Covenant

In the springtime the Arctic National Wildlife Refuge of Alaska comes to life.

Mount Michelson looms over caribou on the coastal plain. As many as 120,000 animals belong to the Porcupine herd, named for the Porcupine River, which flows across the southeastern corner of Alaska's Arctic National Wildlife Refuge. Each spring the animals travel northward and congregate on the coastal plain in the refuge and in adjacent Canadian territory.



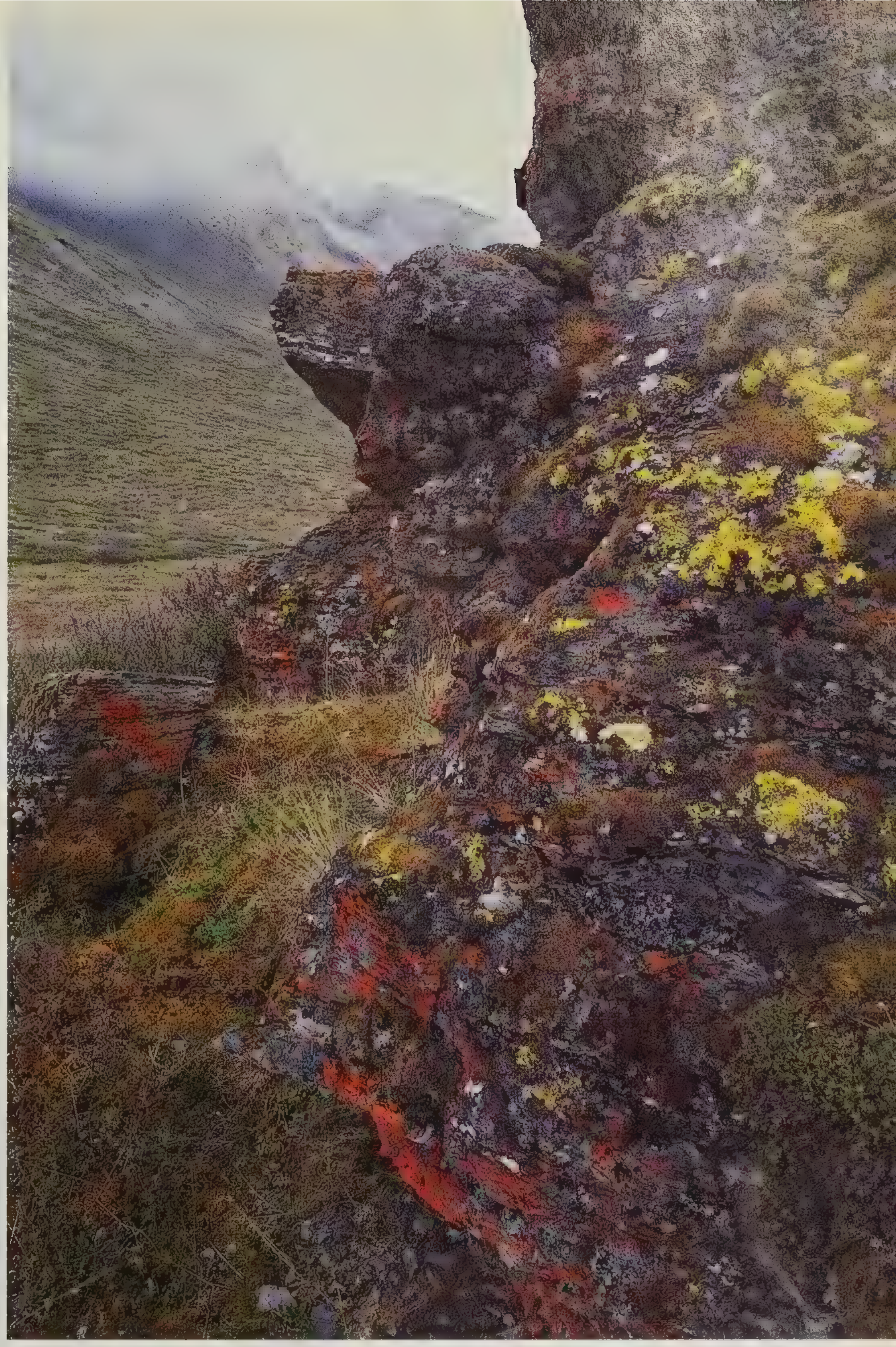
Arctic fox in its summer coat

Marsh fleabane grows in the valley of the East Fork of the Chandalar River, which flows south of the refuge to join the Yukon River. In the distance, Nichenthraw Mountain and spruce trees are reflected in an unnamed lake.

In the fall 300,000 snow geese stop in the coastal plain of the refuge to bulk up on the root stalks of tall cotton grass before heading south to their wintering grounds.

Standing among sharp-edged peaks, at the convergence of mountain and sky, I am alone at a place without roads or people, not even trails except those trodden by wild sheep and caribou; there is nothing to violate the peace, with the mountains still unaffected by humankind. Here one can recapture the rhythm of life and the feeling of belonging to the natural world.

—GEORGE B. SCHALLER



Rock lichens in the valley of the Hulahula River, which flows northward across the coastal plain and empties into the Beaufort Sea.

A male buff-breasted sandpiper makes his courtship display. The world population of the species is only about 15,000. The birds migrate each year from Argentina to the coastal plain of northeastern Alaska and adjacent Canada.

Big predator species such as the polar bear and wolf signify the biological health of the Arctic ecosystem. But to me, in such a harsh environment, the smaller life-forms such as the American dipper, a songbird I saw feeding on the open waters of the Hulahula River in November, signify its spiritual health.

—SUBHANKAR BANERJEE

These photographs by Subhankar Banerjee will soon be published in Arctic National Wildlife Refuge: Seasons of Life and Land *(Seattle: The Mountaineers Books, 2003).*

REVIEWS

Happy Birthday, DNA!

Return with us now to those thrilling days of discovery, fifty years ago this month.

By Everett I. Mendelsohn

James D. Watson opened his irreverent and at times malicious popular book, *The Double Helix,* with the comment: "I have never seen Francis Crick in a modest mood." Watson was referring of course to his partner in the discovery of the structure of DNA. The narrative is clear: immodesty led to success. It is that singular success that is now being celebrated, the fiftieth anniversary of the three papers on DNA (one by Watson and Crick, one by Maurice Wilkins and two coauthors, and the third by Rosalind Franklin and a coauthor) originally published in the journal *Nature* on April 25, 1953.

The tone of the papers, obviously constrained by the editorial policies of what was at the time indisputably the premier journal of science, was subdued if not comically understated:

> We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

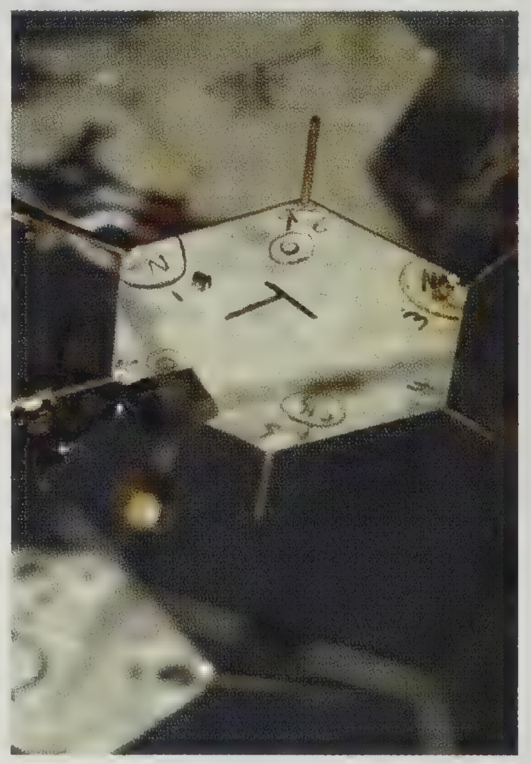
Watson and Crick knew, however, that if their structure was correct, they were on to something very big, and in one of the last paragraphs of their "Letter" to *Nature* they stated their claim:

> It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

One could almost say, "The rest is history." The details sketched by Watson and Crick relatively rapidly stimulated enormous amounts of experimentation and further theorizing. Yes, their discovery does mark a critical milestone in the coming age of molecular biology. The combined effort is as important as any discovery in twentieth-century science. The detailing of the double helical structure of DNA in 1953 and its implications for how genetic information is replicated marked the opening of a major shift in how genetics would be practiced. Prior to 1953 the replication process was "black boxed." In contrast, following the work of Watson, Crick, Wilkins, and Franklin, genes were understood as molecules, and the search for how the molecules functioned and how they influenced the development of the structures and processes of living organisms became the focus of the new, very active, and very large field of molecular biology. Numerous Nobel Prizes were awarded for the scientific discoveries that resulted, and numerous patents were granted for the application of the new science to medicine, agriculture, and commerce.

Watson and DNA: Making a Scientific Revolution
by Victor K. McElheny
Perseus Publishing, 2003; $27.50

Rosalind Franklin: The Dark Lady of DNA
by Brenda Maddox
HarperCollins, 2002; $29.95



James Watson and Francis Crick's 1953 molecular model of DNA, made up of metal plates and rods, arranged helically around a retort stand. Each plate represented one of the four bases whose complementary arrangement "suggest[ed] a possible copying mechanism for the genetic material."

Victor McElheny's book *Watson and DNA: Making a Scientific Revolution* is the first full biography of Watson (Crick has yet to be the subject of a full biographical account). In McElheny's account, Watson's is a long and eventful life in science: the DNA discoveries; the appointment at Harvard; the years as director of the Cold Spring Harbor Laboratory on Long Island, New York, during which Watson oversaw its reconstruction as a leading center for biological research; and the vigorous efforts he made as the first director of the Human Genome Project.

In their initial paper Watson and Crick conceded that they had not done experimental work on DNA, nor had they collected X-ray data; rather, they relied on previously published data. In their final paragraph they note:

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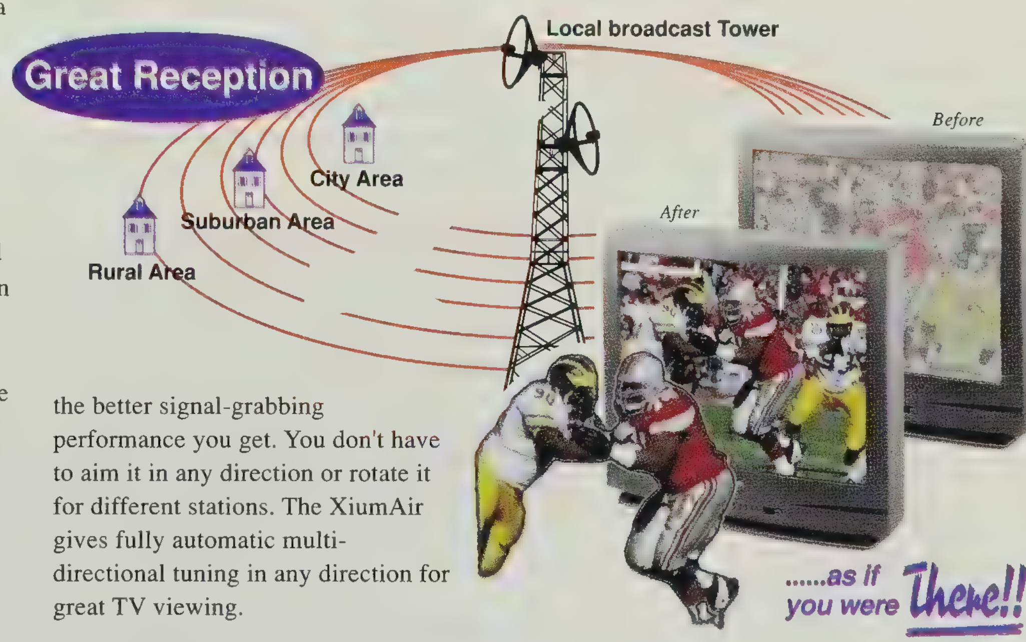

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consequences of the building of the Panama Canal. That an "upscale" rainforest could be reduced in ninety years to a Jurassic-like, low-rent district in terms of biodiversity is instructive. Public works projects in the United States offer similarly dramatic examples of these inadvertent experiments in ecology. Lake Powell and Lake Mead comprise 500 square miles of lake where once "a river ran through." Now fish swim around in Anasazi ruins, and exotic vegetation and invader species of mollusk blur the natural order, creating a biological cacophony where once a desert symphony played. But there's a bright side: electric power galore. Now we can catch the nature channels in Phoenix and see the lights of Las Vegas from space.

Fish may swim around Anasazi ruins flooded by dams, but at least the dams enable us to catch nature channels.

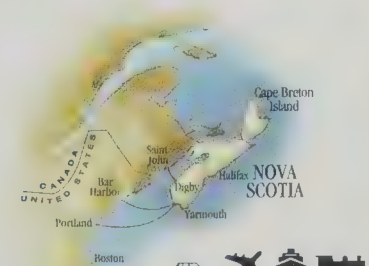
Daniel J. Lenihan
National Park Service
Submerged Resources Center
Santa Fe, New Mexico

I am not so sure, as Messrs. Leigh and Ziegler maintain, that more than 150 million years ago there were no mutualistic associations between plants and animals analogous to the ones observed today. In late Pennsylvanian deposits (beginning about 298 million years ago), in which plant tissues are preserved in considerable anatomical detail, there is evidence for intricate associations. One example, from the Calhoun Flora of Illinois, is a seed fern that bears prepollen (a kind of microspore) far bigger than any known wind-dispersed pollen. The prepollen was produced in large organs that were evidently pierced by a large piercing-and-sucking insect. Furthermore, fecal pellets in the same deposit contain the same or similar prepollen. Do such findings simply point to pollen eating, or was the insect providing a mutualistic benefit to the plant as well?

Conrad C. Labandeira
Smithsonian Institution
Washington, D.C.

ERRATUM: The caterpillar pictured on page 55 of "Biosphere III" (February 2003) should have been identified as belonging to the family Saturniidae, not Limacodidae.

Natural History's *e-mail address is nhmag@amnh.org.*



CONTRIBUTORS

An acclaimed photographer as well as a tropical ecologist, **CHRISTIAN ZIEGLER** ("The Natural Moment," page 6) spends part of the year based on Panama's Barro Colorado Island, where he recently collaborated with Egbert Giles Leigh Jr. on *A Magic Web,* a book about the biodiversity of the island's rainforest. More of Ziegler's work can be seen at www.naturephoto.de.

GABRIELLE WALKER ("The Day the Earth Froze Over," page 44) has traveled to all seven continents in search of stories about science. She has been to the South Pole, climbed trees in the Amazon rainforest, and pulled fresh lava from a volcano in Hawaii with a rock hammer. Walker, who earned her doctorate in natural sciences from the University of Cambridge, has been an editor at *Nature* and the features editor at *New Scientist,* for which she now acts as a consultant. Last fall she was a visiting professor in the geosciences department at Princeton University. *Snowball Earth,* from which her article has been adapted, is her first book.

A transplanted Virginian, **LAURA SESSIONS** ("Date with Extinction," page 52) has lived in New Zealand since 1996. After earning her master's degree in botany at the University of Canterbury in Christchurch, she began working on a doctorate in science communication, which she expects to complete this year. Sessions lectures on ecology and coordinates and leads tours for groups of American ecology students. "I was first introduced to New Zealand through one of these programs," she says, "so it is a great pleasure to introduce other students to such a beautiful place." Her article in this issue is her third contribution to *Natural History.*

"You may be wondering how a young man from Calcutta ended up taking photographs during Arctic blizzards," says freelance photographer **SUBHANKAR BANERJEE** ("Arctic Covenant," page 58), now based in Bellevue, Washington. "In my life, there are no straight lines. In the American Southwest, where I went to pursue graduate studies in science, I was drawn to the wide-open spaces. I began capturing nature on film. I was lured north by a passion to witness polar bears in an untrammeled landscape." Banerjee's work in the Arctic will culminate May 2 with the opening of a solo exhibition at the Smithsonian's National Museum of Natural History in Washington, D.C., and in the publication of the accompanying book, *Arctic National Wildlife Refuge: Seasons of Life and Land* (The Mountaineers Books). The exhibition is scheduled to travel to New York City's American Museum of Natural History in November.

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By Stéphan Reebs

INCREDIBLE JOURNEY II Here's one for the record books: longest documented travel in the wild by a wild mouse. The new world-record holder is a three-quarter-ounce female white-footed mouse that took just a month to travel at least 9.2 miles across a stretch of New England forestland.

Chronicling the achievement was Thomas J. Maier of the USDA Forest Service's research station in Amherst, Massachusetts, who trapped, tagged, and recaptured the peripatetic rodent. Most often it's the males that travel long distances, generally to avoid other males and to seek a mate, but Maier's mouse, too, had good reasons for her trek: the local mouse population had burgeoned, autumn food supplies were low (acorns were in particularly short supply), and the females in nearby areas, suffering equally scarce resources, were in no mood to be welcoming.

A vagabond's search rewarded

A potential competing claim: another white-footed mouse once ran the equivalent of twenty-three miles in twenty-four hours, but that was inside a well-oiled running wheel in a laboratory. Maier's adventurer ran mostly through forest, but she also had to cross at least six forest roads, three small streams, a two-lane primary highway, and a power line right-of-way. ("Long-distance movements by female white-footed mice, *Peromyscus leucopus,* in extensive mixed-wood forest," *Canadian Field-Naturalist* **116:**108–11, 2002)

YOUR PLACE OR MINE? Think of the word "household," and the associations that usually come to mind are positive: warmth, safety, sharing, interconnectedness. But conservationists are beginning to understand the word in a negative way. The problem is that in many "hotspots" of biodiversity—Brazil, south-central China, Florida's Indian River County—where native species are both abundant and threatened by human activities, the number of households is growing faster than the human population itself. That's because today's average household includes fewer people than yesterday's: halve the number of people living as a unit, after all, and you double the number of households, even if the overall population remains constant.

For the most part, that's progress. Households get smaller when standards of living rise, when single people become more affluent, when women become more educated (which not only gives them greater access to paid work but also leads to fewer children), and when fewer generations live together under the same roof. But there is a downside. As Jianguo Liu of Michigan State University in East Lansing and his colleagues at Stanford University have recently pointed out, more housing units consume more land and more construction materials. And smaller households reduce sharing: each individual uses up more resources. The consequent urban sprawl and energy consumption strain ecosystems and erode biodiversity.

Suburban households, proliferating in Asia

Analyzing United Nations data, Liu and his team note that in sixty-five non-hotspot countries, households and populations grew at similar rates between 1985 and 2000—about 1.7 percent annually. During the same period, though, seventy-six hotspots grew, on average, at the annual rate of 1.8 percent in population but 3.1 percent in number of households. The reduction in household size alone (from 4.7 to 4.0 people per household, on average) resulted in 155 million additional residences established in those hotspots in the final fifteen years of the twentieth century—bad news for the flora and fauna. ("Effects of household dynamics on resource consumption and biodiversity," *Nature* **421:**530–33, January 30, 2003)

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We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M.H.F. Wilkins, Dr. R.E. Franklin and their coworkers at King's College, London.

Maurice Wilkins, who did important work on the X-ray crystallographic analysis of DNA, went on to share the Nobel Prize with Watson and Crick in 1962. Rosalind Franklin, a colleague of Wilkins's at King's who had produced some of the clearest X-ray pictures of DNA, died young, of ovarian cancer, on April 16, 1958. Franklin had been a focus of parody in Watson's *Double Helix*, but her pictures had been shared with Watson and Crick, and they proved to be crucial in confirming their structural analysis of DNA. Unable to defend herself from the grave, she became a feminist icon and the subject of two biographies; Brenda Maddox's *Rosalind Franklin: The Dark Lady of DNA* is the more recent.

Watson (right) and Crick in 1953, shortly after working out the structure of the DNA molecule

It is fitting that these two biographies are part of the public record of the fiftieth-anniversary celebrations. And there is little doubt that Watson and Crick will get the lion's share of attention—after all, they are both still alive and active, and both have enjoyed long and quite successful careers since their youthful discovery. Yet I'm not sure either of them is entirely comfortable sharing the limelight with Franklin. The irony is that Franklin looms as large as she does today in part because of the way Watson portrayed her in *The Double Helix*.

Maddox recounts Watson's first encounter with Franklin, which took place at a lecture she gave as part of a colloquium at King's College. Watson, in recalling the lecture for his book, betrays something of his attitude toward women: "Momentarily I wondered how she would look if she took off her glasses and did something novel with her hair." But he says little or nothing about the stunning X-ray pictures she had made and which he hoped would give him the evidence he and Crick needed to support their developing theory of a helical structure for DNA.

Instead, Watson went on to belittle Franklin's dress and her lack of "lipstick to contrast with her straight black hair." Maddox concludes that "Watson could not have given the world his 'Rosy' if Rosalind had been alive." A number of scientific colleagues, as well as friends and family of Franklin's who were sent copies of the draft manuscript, protested Watson's account of Franklin, as well as his references to others. In response to his critics Watson added what Maddox calls "a pious epilogue," which was published with the first edition of the book in 1968. From that historical vantage, Watson writes, virtually everyone mentioned in the book was still alive, with "one unfortunate exception. . . .:"

Rosalind Franklin died at the early age of thirty-seven. Since my initial impressions of her . . . (as recorded in the early pages of this book), were often wrong, I want to say something here about her achievements.

The rest of the paragraph and the concluding one that followed tried to make amends, but the text in the body of the book remained unchanged.

But if Watson had been so clearly nasty and catty about Franklin that he now sought to apologize, he seemed unmoved by the anger both Wilkins

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and Crick expressed at the book's tone and content. In a vivid section of his biography, McElheny chronicles their reactions. Wilkins thought *The Double Helix* should not be published. It was "extremely badly written, juvenile, and in bad taste." Crick, McElheny notes, was even more savage: "It shows such a naïve and egotistical view of the subject as to be scarcely credible." And perhaps most tellingly, it "grossly invades my privacy. . . . [It was] a violation of friendship." Several years later, in an article in *Molecular Biology* celebrating the twenty-first anniversary of the 1953 paper, Crick confessed that he too had contemplated writing a book. He had gotten as far as a title, *The Loose Screw,* and the opening line: "Jim was always clumsy with his hands. One had only to see him peel an orange. . . ."

If the text of *The Double Helix* is what brings these two biographies together at one moment in time, there is no question that both of them go far beyond that text. Both are filled with detail, much of it previously unknown or only hinted at. Each one provides valuable historical appraisals of both Watson and Franklin by members of the founding generation of DNA studies, as well as by subsequent generations of practitioners. The interviews noted by each biographer are prodigious and in many cases add context and color.

But the two books are also quite different. McElheny's is one of heroism mixed with quirkiness; Maddox's one of tragedy and attempted reconstruction. Both directly and implicitly offer accounts of how science operates, how its practitioners behave, how its institutions function (or malfunction), and how myths are made and destroyed. McElheny's focus is a man who is at once both immodest and ill at ease. Although McElheny is at pains to avoid discussion of Watson's private life and family, his subject's personal immaturity and curious attitude toward women cannot be overlooked. (Watson's most recent volume of "autobiography," titled *Genes, Girls, and Gamow,* is further illustration of the type.)

McElheny has known Watson for more than four decades, covering him first as a science reporter for *The Boston Globe* during Watson's years at Harvard. He also spent four years working for Watson at Cold Spring Harbor. Although he thanks Watson for years of friendship, he is also at pains to point out that "Watson did not participate in this project." That may be literally true, yet Watson clearly gave his blessing to this biography. He steered McElheny to many colleagues who gave extensive interviews and who helped review the manuscript. He still directs the archives at Cold Spring Harbor, and made sure McElheny could make good use of them through unencumbered access. Accordingly, though *Watson and DNA* is not an "authorized" biography, it is one composed from deep within the molecular-biology community.

X-ray diffraction photograph of DNA. This image of the B form of DNA was obtained by Rosalind Franklin in 1953, and was a crucial piece of evidence supporting the structure proposed by Watson and Crick.

McElheny wants to insist that there is much more to Watson than his reputation as "biology's bad boy," and the book is bracketed with tales of honor and scientific recognition. McElheny opens with an account of the lecture Watson was invited to give at Harvard in George Wald's introductory course on biology, on the day after Watson's Nobel Prize was announced in October 1962. The book closes as Watson is made an honorary Knight of the Order of the British Empire, in January of last year. In between, McElheny does a thorough job of pulling together an account of the 1953 discovery of the structure of DNA, integrating into it the views of many others, both contemporary and later. Taken together with the "formal" histories of that discovery (by Robert C. Olby of the University of Pittsburgh and by Horace Freeland Judson of George Washington University), McElheny's book adds valuable elements to the story of how that important work was accomplished.

But to his credit, McElheny also gives full rein to the many manifestations of "brat/genius" behavior (his words) and the criticisms of it. According to McElheny, Watson's "bad boy" image is richly deserved, and in part self-inflicted (perhaps self-crafted is more accurate) in Watson's two autobiographical volumes. McElheny is also well aware of the controversy arising out of Watson's (and Crick's) failure to appropriately recognize the work of Franklin, as well as the contingent nature of the discovery itself. He notes Watson's own retrospective judgment: "We were lucky. I don't think it was any great intellectual insight." And elsewhere, Watson said: "The DNA structure was ready to be solved. I can't imagine two years going by [after 1953] without someone else making the discovery."

Brenda Maddox moves directly into the territory that McElheny eschewed in his volume. She explores the life, work, and personality of Franklin. A strong-minded, complex, and highly intelligent woman, Franklin was born into a prominent, well-to-do and well assimilated Anglo-Jewish family. Her biographer locates her in time, in place, and in culture.

Her father's family had come to England from Breslau, in Silesia (now part of southwestern Poland), in 1763 and prospered through the generations in banking and publishing. One of her relatives was the first high commissioner of Palestine. Her mother's family included the first Jewish professor at an English university and the first Jewish lord mayor of London. There were suffragists and socialists, a trade union organizer, and a London city councillor in her heritage.

Maddox looks at length at Franklin's early career and provides a detailed and sympathetic account of her unhappy (albeit, coincidentally, highly productive) years from 1951 until 1953. She spent those years at King's College working with Wilkins, and most of her encounters with Watson and Crick took place there. They were stiff and unfriendly meetings, and led Crick to refer to Franklin as "that dark lady"—the phrase Maddox adopts as a subtitle. Franklin's move in 1953 to Birkbeck College, London, and to the laboratory of the crystallographer J.D. Bernal, provided a much friendlier and more supportive environment, where her talented research continued.

But by then Franklin's work with DNA had ceased. Instead, she began to carry out quite successful studies of the structure of tobacco mosaic virus (she located the infective element of the virus in its ribose nucleic acid). Part of what is known about Franklin's work of that period comes from two obituaries Bernal wrote at the time of Franklin's death, one for *The Times* of London and the other for *Nature.* In both he recounted her scientific work, and dealt delicately but fairly with how credit had been assigned for the discovery of the helical structure of DNA. As Bernal summed up her contributions:

> As a scientist Miss Franklin was distinguished by extreme clarity and perfection in everything she undertook. Her photographs are among the most beautiful X-ray photographs of any substance ever taken.

Rosalind Franklin in an undated portrait

Franklin is well served by Maddox's intelligently written and eminently fair biography.

Many commentators have asked whether Franklin would have shared the Nobel Prize with Wilkins, Watson, and Crick had she been alive in 1962 (the Nobel Prize is never awarded to a deceased scholar). Still others have contested whether she would have deserved it. Counterfactual history seldom yields adequate answers, and I see little point to indulging in it here. But the wisdom of fifty years of hindsight does allow several incontrovertible observations.

The very fact that the Nobel Prize for physiology or medicine was split three ways and the chemistry prize in the same year was shared by the biochemists Max Perutz and John Kendrew for their work on the structure of proteins, illustrates how much scientific activity was focused on cracking the structures of important biological molecules. The chemist Linus Pauling, already a Nobel laureate for work that led to the elucidation of the helical structure of proteins, was also racing to find the structure of DNA.

Although the high drama in the story of Watson, Crick, Wilkins, and Franklin arises, in part, from the remarkably different styles and temperaments of the personalities involved, the science on which they were working was yielding answers to each one of them. The history of the discovery is certainly linked to individuals, but, in this case particularly, it also transcends them. One indication of how far along the research was on several fronts was the simple fact that a single step taken by the original group (Watson and Crick) was able to meet with such complete success. As the biochemist John Edsall remarked in 1962: "No fundamental revision of the picture has been required since the early formulation of Watson and Crick." That assessment remains largely true to the present day.

Of course, even after fifty years key elements of the molecular processes of reproduction and development are still being sought. Efforts to modify organisms through molecular manipulation—genetic engineering—are being widely practiced in agriculture, and more circumspectly experimented with in medicine. Virtually all these developments have been controversial. Genetically manipulated foods have been greeted with stiff resistance in Europe, even while they have been much more readily accepted in the United States. Genetic manipulation in humans—gene therapy—has met with only mixed success, as well as with some highly visible failures. It has also brought into sharp focus the ethical issues raised by seeking to treat genetically linked diseases via the genetic engineering of human beings. Not yet tried, but even more controversial, would be any scheme to engineer the future by genetically manipulating the reproductive cells. The genetic revolution begun in 1953 is unlikely to have run its course, either scientifically or culturally, by the time our grandchildren celebrate its one-hundredth anniversary, in 2053.

Everett I. Mendelsohn is a professor of the history of science at Harvard University. He has worked extensively on aspects of the social and sociological history of science and the relations between science and modern societies.

Among Stone Giants: The Life of Katherine Routledge and Her Remarkable Expedition to Easter Island
by Jo Anne Van Tilburg
Scribner, 2003; $26.00

Almost a century has passed since Katherine Routledge and her husband Scoresby raised the anchor of their custom-built ninety-foot schooner *Mana* and set sail for adventure. Few Europeans had ever visited Rapa Nui, as the local residents called Easter Island, but all Victorians with an ounce of romance in their soul knew of the island's alluring riddle. Katherine hoped to solve it.

Although Rapa Nui had no trees, it had a forest: hundreds of huge stone statues were scattered across its barren landscape. Who had carved these otherworldly monuments? And what purpose—religious, ceremonial, commemorative—could justify such a large investment of labor and resources? The Routledges, possessed of Katherine's inherited fortune as well as the Victorian mania for collecting, were determined to find out. Their expedition made landfall on Rapa Nui, after an eventful year at sea, on March 29, 1914.

Oldest Easter Island statue, on the slope of the volcano Rano Raraku

From the start it was Katherine's show. Although she had little formal training in archaeology, she knew what to look for and how to listen. In her party's seventeen months on the island she made drawings and watercolors of each landmark. She sat daily with village elders, compiling notebooks of their replies to her questions about the old ways, the ancient gods, how the island and its people came to be. While Katherine sketched and scribbled, Scoresby collected artifacts from caves and burial sites, and members of the *Mana*'s crew photographed and mapped with military precision. It was the first true attempt to conduct an archaeological survey of the island.

Van Tilburg has dug deeply into Katherine's family records and the notebooks of the *Mana* expedition to present a convincing picture of science as it was practiced in an era when natural history was a popular sport of the moneyed class. Because government funding was rare, wealthy amateurs, rather than professional associations and peer reviewers, set research agendas. Today's field-workers may employ far more culturally sensitive and environmentally sound techniques than did the Routledges, who looted gravesites with abandon and spaded like gardeners through delicate layers of artifact-bearing earth. But a well-managed expedition today would be hard-pressed to provide as colorful a cast of characters, or grist for such a lively story.

Scoresby was arrogant and tactless; the crew of the *Mana* was mutinous (usually in response to Scoresby's outrageous behavior); Katherine was often sidelined by bouts of hallucinations and depression. The islanders staged an armed revolt during Katherine's stay. By the time the couple's seventeen months came to an end, war-torn Europe must have seemed like a haven.

Later archaeological surveys did better work than the *Mana* expedition, and the history of Rapa Nui has since been convincingly linked to Polynesian cultures to the west, making Easter Island seem a bit less mysterious and remote. But Katherine Routledge's work stands the test of time. In a letter to her mother, written as she was packing to leave the island, Katherine wrote: "If people ask you if we have 'solved the riddle,' you can say that we do not claim to have done that, but we have found much that is new & interesting." That is an apt description both of Routledge's work and of Van Tilburg's elegant and compelling biography.

Tycho & Kepler: The Unlikely Partnership That Forever Changed Our Understanding of the Heavens
by Kitty Ferguson
Walker & Company, 2003; $28.00

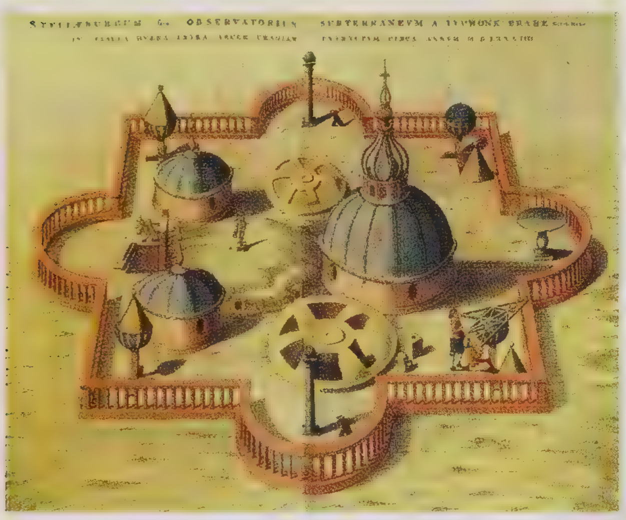
When Copernicus first proposed a universe with the Sun at its center in 1543, most of his sixteenth-century contemporaries regarded the idea as interesting but hardly revolutionary. Geometrically, it made little difference whether the Sun or the Earth stood still, and the crude observations of the time offered precious little evidence for telling one case from the other. Even those partial to a sun-centered scheme hedged their bets by harrumphing, at least in public, that, yes, this Copernicus was a clever fellow, but whatever the merits of his model, it was, after all, only a model. God could have chosen to make the Earth revolve around the Sun—but simply didn't.

In private, though, some of his contemporaries believed He did. Tycho Brahe, a Danish nobleman and amateur astronomer, thought Copernicus might be on to something. Tycho had seen a new star appear in the heavens in 1572, and he determined that it lay far beyond the Moon, in a region of the firmament where, according to the conventional

EXPLORER GUIDE

astronomy of his day, nothing ever changed. Convinced that the old picture of the Earth-centered universe needed repair, Tycho proposed a hybrid system in which the Sun carried the orbiting planets around a stationary Earth. But Tycho knew that his proposal would be just another clever model without the support of careful astronomical measurements—measurements Tycho, with the right resources, would be happy to make.

King Frederick II of Denmark provided the money Tycho needed for his purposes, and granted him the little island of Ven (formerly Hven), at the mouth of the Baltic Sea, within view of Hamlet's fabled castle, Elsi-



Observatory of Tycho Brahe, 1546–1601

nore. There Tycho erected a battery of precise sighting devices (the telescope had not yet been invented); for almost thirty years, he and a staff of assistants compiled nightly observations of the positions of the planets.

As the data accumulated, however, Tycho found he lacked the mathematical skills, not to mention the time away from his aristocratic lifestyle, to make the calculations he needed to prove his point. By the last decade of the sixteenth century, the fifty-year-old astronomer was facing a midlife crisis, afraid that immortality was slipping from his grasp. Nicolaus Reimers Bär, a former assistant, had written a scurrilous book claiming Tycho's system as his own. Worse, Denmark had a new king, who was not inclined to continue his father's royal indulgence of Tycho's expensive hobby.

So Tycho packed up and wandered through Europe, eventually stopping in Prague. There he found a patron in Rudolph II, the Holy Roman Emperor—and, just as important, a new assistant named Johannes Kepler. Twenty-five years Tycho's junior, Kepler was an impoverished German mathematician on a quest to prove his own pet theory about the motions of the planets.

Science writer Kitty Ferguson begins her book with this meeting of Kepler and Tycho, and continues in flashbacks of the lives of the two great figures viewed against the unsettled backdrop of post-Reformation Europe. Taken separately, as many earlier biographers have done, the stories of the two astronomers seem merely eccentric: Tycho's artificial nose and Kepler's mother's trial for witchcraft are the only details my students usually remember. But Ferguson's approach, enlivened with the dramatic pacing of a mystery novel, shows beautifully how the obsessions of the pragmatic, imperious Brahe meshed perfectly with the obsessions of the idealistic, pensive Kepler.

They were an odd couple, indeed, and Tycho, weary and wary of the world by the time they met, resisted full collaboration with the young Kepler to the very end. As it was, he died scarcely a year after their meeting, and Kepler became heir to the finest observations of the planets ever made. From those, he showed conclusively that the Earth and the planets orbited the Sun—though in elliptical orbits, not the circular ones Copernicus preferred. Kepler's laws led, in turn, to Newton's laws of motion, which laid the groundwork for modern physics and cosmology. If the story of Tycho and Kepler was, as Kitty Ferguson's subtitle states, an "unlikely partnership," it was nonetheless a marriage made in heaven.

Smokechasing
by Stephen J. Pyne
The University of Arizona Press, 2003; $37.50

When the harmattan blows south from the Sahara, nighttime satellite images of Ghana and Nigeria light up like fireflies on a summer's evening: West Africa is burning. The harmattan is a dry wind in a dry season. Later, when the rains return, fires can still be sparked by lightning, but most of the harmattan fires are set by rural agriculturists, who recognize and welcome their help in clearing and fertilizing their fields. The fires complete a cycle as old as respiration itself, for both the carbon-rich detritus and the oxygen that burns it ultimately come from plants, making wildfire a closing step in the process of respiration. From a global perspective, fire is an integral element of the biosphere, an essential cog in the marvelous engine that gives life on Earth its dynamic stability.

For those of us who live in cities, that truth is far from obvious. In an urban setting fire is a disaster, but in the wilderness, fire takes on quite a different function. It is best regarded as a tool of control, not an evil to be eliminated. One of the paradoxes of rural fires is that, by trying to eliminate them, we make them worse when they do occur: in the year 2000 wildfires in the United States burned at least seven million acres, called out 30,000 firefighters, and cost the nation more than $2.5 billion. Many were kindled in areas where dry undergrowth had accumulated for decades, the result of aggressive fire control. Smokey Bear should have been sued for negligence.

If informed opinion is more sensitive to such issues nowadays, the credit is due in large part to Stephen Pyne, our most eloquent narrator of the natural history of fire (a branch of literature he almost single-handedly created). His style is recognizable by its heavy load of metaphor and by its

William Buckleyesque use of recondite, albeit evocative, language. (As I read the book, my notepad quickly filled up with unfamiliar words and phrases: "swiddeners," "impauperate," and "lithic horizon," to mention a few.)

Readers of Pyne's earlier books will hear echoes of many familiar themes in *Smokechasing,* a collection of miscellaneous essays from recent journals and magazines. Some show how the approaches of developing countries must differ from those in the industrialized world, both in learning to manage fire and in reconciling the priorities of public forest preserves with the concerns of private industries that depend on forest products. Other essays deal with the growing problem of "intermix" fires that burn in places such as the canyons of California, where urban sprawl has turned forested areas into residential compounds. And a few of the essays are just rousing good stories of fires and of firefighters.

Forest fire in Spain

Yet Pyne remains on message, always returning to his point that good public fire policy must strike a balance between total suppression and uncontrolled burning, and urging that such a policy be set locally, to meet local needs. Whether or not you've heard all this before, it's rewarding to hear it again, if only for the pleasure of a prose style that slices through tangled thickets like a bulldozer clearing a fire line, and lights up the darkness like a blazing forest.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

nature.net

Oil to Burn?

By Robert Anderson

Daniel Yergin, writing at the end of the 1990–91 Gulf War, concluded his monumental history of oil, *The Prize: The Epic Quest for Oil, Money, and Power,* with this prediction: "The fierce and sometimes violent quest for oil—and for the riches and power it conveys—will surely continue so long as oil holds a central place." How long that would be, he made no bets. As I write, a second war with Iraq is contemplated. According to some expert prognostication on the Web, the king of natural resources may, once again, be consumed and wasted in spectacular wildfires.

At its height, the Kuwaiti inferno burned oil at a rate equivalent to 10 percent of total world demand. Jonathan Lash, president of the World Resources Institute (www.wri.org), foresees the possibility of a similar catastrophe if war comes again, as he writes in his article "The Environment: Another Casualty of War?" (click on "About WRI," at left, then click on "From the President").

Forbes magazine's Paul Klebnikov (forbes.com/global/2002/1028/024_print.html) sketches the mammoth size of the Iraqi reserves, which may ultimately exceed those of Saudi Arabia. He also notes that the fields currently producing in Iraq have the world's lowest "lifting costs": the expense of extracting a barrel of low-sulfur crude from rock formations. Iraq's reservoir is so shallow that the lifting cost is under a buck. Compare that with $2.50 in Saudi Arabia and between three and four dollars in the Gulf of Mexico and the North Sea. The ease with which Iraqi oil shoots to the surface doesn't bode well for the environmental devastation that will take place if these fields are set ablaze.

Regardless of its scale, such a disaster wouldn't make much difference to global petroleum stocks, which took hundreds of millions of years to accumulate. By most reasonable estimates, peak world oil production is just a few years away. For detailed background on oil as a finite resource, go to hubbertpeak.com, named for the petroleum geologist who correctly predicted the 1970 peak in U.S. production. The information on the site makes it disturbingly clear that oil will follow the pattern typical of other finite resources: its extraction rate will reach a high and then dwindle to nothing. Similar dire predictions (but more attractively displayed) are outlined by James J. MacKenzie in "Oil as a Finite Resource: When Is Global Production Likely to Peak?" (www.wri.org/wri/climate/jm_oil_001.html), another page on the WRI site. Don't miss the links on the right for the text and slide show of MacKenzie's project "Thinking Long Term." Humanity will soon be on the downward slope of the oil age. How we all cope with that will be the story of the century.

Robert Anderson is a freelance science writer living in Los Angeles.

Warp Factor

A spinning dwarf may have twisted our galaxy's disk.

By Charles Liu

An edge-on view of the spiral galaxy ESO 510-G13, in the constellation Hydra (visible from the Southern Hemisphere), shows the warp in its disk, much like the warp in our own Milky Way. The warp suggests that ESO 510-G13 may have swallowed another, smaller galaxy in its past.

Astronomers sometimes describe the shape of our home galaxy, the Milky Way, as a thin-crust pizza with a plum stuck in the middle. The plum is the slightly oblong central bulge, protruding about 3,000 light-years above and below the galactic plane, comprised mostly of older stars; it makes up the core of the Milky Way, and includes a black hole two and a half million times the mass of the Sun. The crust of the pizza is the galactic disk—the source of most of our galaxy's light. Thin and flat, the disk is 100,000 light-years across, about 1,000 light-years thick, on average, and includes more than 80 percent of the galaxy's hundred billion or so stars.

The plum-and-pizza picture works well enough, but like most simple metaphors, it breaks down if you push it. For one thing, the galactic disk isn't a rigid body, but a loose agglomeration of matter streaming around a common center of gravity. (The swirling pattern of a hurricane far better resembles our spinning galaxy than a flying Frisbee does.) For another thing, our galaxy's disk isn't flat; it's warped, like an old-fashioned phonograph record left out in the hot sun. Picture that sun-baked record spinning on a turntable—or a disk of pizza dough spun into the air by a skilled chef: our galaxy goes through the same kind of floppy, wobbly gyrations, though at a rate best measured in revolutions per hundreds of millions of years.

Why does the Milky Way have such an odd-looking warp? We astronomers have been puzzling over that question for decades, but no definitive answer has emerged. One thing we do know: when it comes to warps, our galaxy is hardly unique. About half of all spiral galaxies are warped to some degree. Theoretical and computational models have shown that a number of physical processes can warp a galaxy, so it's a matter of figuring out which scenario applies. Now an innovative new analysis of the problem by Jeremy Bailin, an astronomy graduate student at the University of Arizona in Tucson, has implicated a small satellite galaxy, currently being ripped to shreds by the gravity of the Milky Way.

The Sagittarius Dwarf Spheroidal Galaxy, so named because of its shape, size, and location in the sky, was discovered in 1994. It appears to be in a roughly polar orbit around the Milky Way—that is, above and below the galactic disk—about 50,000 light-years from the galactic center. That orbit brings the dwarf galaxy far too close to the huge gravitational tidal forces of the Milky Way for the dwarf to remain intact. As a result, the Sagittarius Dwarf now looks something like strands of spaghetti spilling from the front of a pasta-making machine, the galaxy's matter being drawn out over hundreds of millions of years by intergalactic tides.

Gravitational collisions between small satellite galaxies and big spiral galaxies have long been regarded as possible culprits in the warping of a larger galaxy's disk. The best known satellite galaxies orbiting the Milky Way—the Large and Small Magellanic Clouds—are too far away, and have the wrong orbital characteristics, to have warped our galactic home. The Sagittarius Dwarf seems a much more likely candidate, simply because it is only a third as far from the center of the Milky Way as the Magellanic Clouds. But in astronomy—unlike in real estate—location isn't everything; to show a direct connection between warp and dwarf, the orbital motion of the Sagittarius Dwarf must be linked to the rotation of the Milky Way's disk.

Bailin's study is the first to find such a link. His analysis of the galactic warp is based on angular momentum—a measure of how much a system is spinning or rotating. Just as objects moving

in a straight line have momentum, objects spinning or orbiting around an axis have angular momentum; and just as the momentum of two objects combine when they collide, so too does their angular momentum. Imagine two figure skaters coming together for a combination spin. When they make physical contact, their individual spiraling motions combine to produce a single, unified whirl.

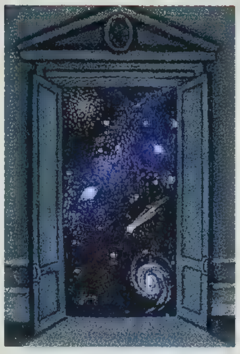
Starting with the latest measurements of the structure and spin of the Milky Way, Bailin deduced the angular momentum of the warped portion of the Milky Way's disk. He then compared that measure with the angular momentum of the Sagittarius Dwarf—and found for the first time, within the margins of measurement error, that the two angular momenta are identical in both quantity and direction. Such a coupling of the angular momentum of two bodies almost never happens by chance; usually, it takes place only when two spinning systems, like the skaters, come into contact. The coupling isn't enough to prove cause and effect by itself, but it's solid circumstantial evidence that the interaction of the Sagittarius Dwarf with the Milky Way disk created the warp in our galaxy.

With enough spinning, warps in disks eventually disappear. That's why a pizza chef spins pizza dough, tossing it into the air again and again: in time, the thick lumps get spun out, leaving the disk smooth, even, and thin. Someday, that will probably happen to the Milky Way, too. Sooner or later—the latest calculations range from a few hundred million years to a few billion years from now—our galaxy will work out the kink in its disk. That is, unless another dwarf galaxy like Sagittarius appears, coming along with just the right orbit, giving the Milky Way disk just the kick it needs to start warping all over again.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN APRIL

By Joe Rao



Mercury climbs progressively higher above the western horizon every evening at dusk in the first half of the month, but the improving view is offset by the planet's fading brilliance. On the 1st the planet shines at magnitude –1.4; about thirty minutes after sunset, it is very low above the west-northwestern horizon. On the following evening the Moon—visible as an exceedingly thin sliver—hovers about 4 degrees below and to the left of Mercury. On the 16th the planet reaches its greatest elongation (20 degrees east of the Sun) and appears noticeably higher in the sky, but shines more dimly, at magnitude +0.2. For the rest of the month Mercury sinks back down to the horizon while fading rapidly, and is out of sight well before the end of April.

Venus rises like clockwork about an hour before the Sun all month. The planet lingers low in the eastern predawn sky.

Mars—god of war—glares ever more fiercely at the Earth. The pumpkin-colored planet rises in the southeast about four hours before the Sun and nearly reaches culmination by sunrise. Mars is one magnitude, or roughly two-and-a-half times, brighter now than it was on January 1. If your daily routine this month rouses you while the sky is still fairly dark, look to the southeast to watch the planet brighten over April's course from magnitude +0.5 to magnitude 0. At midmonth it stands just 104 million miles from Earth. The planet leaves the constellation Sagittarius, the archer, for Capricorn, the sea goat, on the 21st.

Lordly Jupiter, high in the southern sky at dusk on the 1st, descends toward the west. It starts the month just to the east of the Beehive star cluster, near the center of the faint zodiacal constellation Cancer, the crab. On the 3rd, Jupiter reverses its retrograde, or westward, motion among the stars and begins moving slowly east, away from the Beehive. The waxing gibbous Moon slowly approaches Jupiter from the west—falling for another of Jupiter's famed seductions—in the overnight hours between the 10th and the 11th.

Saturn rides the constellation Taurus, the bull, into April. The planet is readily visible, shining pale yellow at magnitude 0 in the west-northwestern sky during the first half of each night of the month. On April 7, the same night a fat crescent Moon glides well above Saturn, the Earth will finally attain its maximum Saturnicentric latitude. Translation: Saturn's ring system will list at its greatest possible angle toward the Earth, 27 degrees—making for a stunning, brilliant display even through the lens of a small telescope. The last such event took place in September 1988, and the next one isn't due until October 2017. The rings appear to hide the north end of the planet, and stick out a bit behind the south end. Don't miss it!

The Moon is new on the 1st at 2:19 P.M., Eastern Standard Time. It reaches first quarter on the 9th at 7:40 P.M., waxes full on the 16th at 3:36 P.M., and wanes to last quarter on the 23rd at 8:18 A.M. Our satellite reaches perigee at 1:00 A.M. on the 17th, orbiting just 221,937 miles from Earth. Beachcombers, take note. Very high tides can be expected from the coincidence of perigee with the full Moon—a phenomenon known as an astronomical spring tide.

"Spring ahead" in much of Canada and the United States, as daylight saving time returns on Sunday, the 6th. Remember to set clocks ahead one hour.

Unless otherwise noted, all times are given in Eastern Daylight Time.

AN INTERVIEW
WITH MELANIE STIASSNY

Milstein Family Hall of Ocean Life Reopens May 17

D. FINNIN/AMNH

***Melanie Stiassny** is Axelrod Research Curator of Ichthyology in the Division of Vertebrate Zoology and a lead curator of the renovation of the Milstein Family Hall of Ocean Life. She spoke with us about the oceans, the new hall, and the blue whale.*

Q: *You've said that we know more about the dark side of the moon than we know about the ocean.*

A: Which is sadly true. As terrestrial creatures, we tend to think of life on our planet as being essentially life on land. It couldn't be further from the truth.

A little over 70 percent of the Earth's surface is covered in water. We've seen the blue marble from outer space. It's blue because there's so much water on Earth. And 362 million square kilometers of that is marine—the world ocean. Yet perhaps as little as 1 percent of the ocean floor has actually been explored. The ocean as a whole is very much the "final frontier," the last truly wild place on our planet.

It's a place that is not only extraordinary in its dimensions and all of the implications of its size but it's also the place that was the cradle of life on Earth. But instead of everything leaving the cradle, in fact, most things have stayed in the ocean. Most of the life on Earth is still living in the ocean.

Q: *I think most people are surprised by the amount and diversity of life under the water.*

A: It's phenomenal. Estimates vary and, believe it or not, we're not even able to say how many species exist on the planet. But probably about 80 to 90 percent of all life on Earth is found in the ocean. And it's not just the quantity or "biomass"—the actual amount of living material—it's also the diversity, the number of different kinds of living things.

The people visiting the new Hall of Ocean Life are going to be exposed to kinds of organisms that they've never heard of, they've never even imagined. And yet these organisms all work together to create something incredibly diverse and fundamentally important for life on the entire planet.

Q: *When people leave the hall, what do you want them to think?*

A: Well, that's really difficult because there are so many different things. But I want people to walk away with an understanding of how remarkably superlative the oceans really are. Not just in terms of sheer size and beauty, but also in their ecological complexity and the tremendous biological wealth they contain. Perhaps above all, I want them to understand how absolutely critical ocean health is to the health of all life on Earth. The oceans are a series of interconnected ecosystems that can unravel very, very, quickly.

So I also want visitors to the hall to be empowered in a sense, to have an idea of how their behavior as individuals can impact the oceans but how it can also help to save them.

Q: *Can you tell us a little bit about the renovation?*

A: I hope people are going to be very happy when they come back to the hall. This is one of the most beloved halls in the museum—for good reason. We want people to experience all the wonder they felt in the older version, but to be amazed by the new. We didn't want to change it beyond recognition, but we did want to tell a much richer story. By giving the oceans a proper introduction and a real explanation as to what they are, where they came from, how long they've been around, what's living there, and that it all functions as a complex whole, I think that's going to be an eye-opener for many visitors. It's also going to be tremendously beautiful.

I think we steer a very nice path between being absolutely state-of-the-art, but at the same time, keeping this kind of majesty and splendor of the old style of exhibit. I really hope people

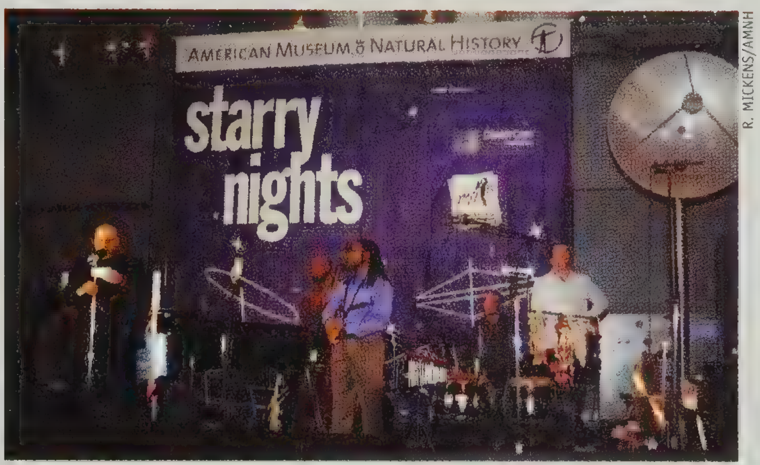
appreciate how much thought actually went into that because we do know how dear much of the old hall was.

Q: *What can you tell us about the centerpiece of the hall, the blue whale model?*

A: As you know, the blue whale is a kind of "jewel in the crown" for this institution. An incredible animal, the largest that ever lived. Ours is a female (they are slightly larger than males). When she was installed in 1969, we knew so little about blue whales that we actually got some of the anatomical details wrong. She had been modeled from a specimen about to be butchered and decomposition had already begun to distort her frame. We've now corrected that, and we've metaphorically released her back into her habitat—the open ocean. Now, when you come into the hall and see this beautiful animal you'll not only learn about blue whales, and whales in general but also about work being done in whale conservation throughout the globe. And you're going to learn about the habitat that the whale lives in. In short, we have really tried to insert all of the organisms that live in the ocean into their ecological context. So that now the blue whale in a sense becomes the ambassador to the open ocean—the largest habitat on our planet.

The magnificent restoration and rejuvenation of the Museum's beloved Milstein Family Hall of Ocean Life is made possible by the generosity of Paul and Irma Milstein. The Museum gratefully acknowledges the critical role of the City of New York, the New York City Council, the Department of Cultural Affairs, and the Borough President of Manhattan in the realization of this project. The Museum deeply appreciates major support from Edwin Thorne and from Swiss Re. Significant support has also been provided by The Marc Haas Foundation, Ruth Unterberg, MetLife Foundation, and Mikimoto. Additional generous funding was provided by Jennifer Smith Huntley, Patricia S. Joseph, William H. Kearns Foundation, Denise R. Sobel and Norman K. Keller, Mrs. Frits Markus, Jane and James Moore, David Netto, Mrs. John Ungar, and the Bristol-Myers Squibb Foundation, Inc.

Starry Nights Hits the Airwaves



WGBO's Gary Walker introduces Antonio Hart and The Antonio Hart Quintet during the February 7 live broadcast of *Starry Nights*.

After three years of crowd-pleasing performances, *Starry Nights,* the American Museum of Natural History's jazz performance series, burst onto the airwaves this winter. The Museum and WBGO Jazz 88.3 FM have teamed up to broadcast select *Starry Nights* performances live from the spectacular Rose Center for Earth and Space where two sets—at 5:30 and 7:00 p.m.—take place on the first Friday of each month. Tune in at 5:30 p.m. on Friday, April 4, for this month's broadcast.

WBGO, the only full-time jazz station in the New York metropolitan area, will carry a total of six live broadcasts this year of *Starry Nights.* February 7 inaugurated the collaboration, and future broadcasts will take place on April 4, June 6, August 1, October 3, and December 5, from 5:30 to 6:30 p.m. Gary Walker, WBGO's *Morning Jazz* host for 13 years and winner of the 1996 *Gavin Report* Jazz Radio Personality of the Year award, will host the hour-long broadcasts.

Starry Nights was launched soon after the Museum opened its acclaimed Frederick Phineas & Sandra Priest Rose Center for Earth and Space in February 2000. The series kicked off with Ray Vega's Latin Jazz Sextet. Since then, over 35 celebrated jazz groups have appeared, including Bobby Sanabria and Quinteto Aché, Jimmy Heath, The Jazz Passengers, Jerry Gonzalez and the Fort Apache Band, and Ray Barretto and New World Spirit. The first WBGO broadcast aired in February 2003 with the Grammy-nominated alto saxophonist Antonio Hart and The Antonio Hart Quintet.

Nearly 1,000 jazz enthusiasts attend *Starry Nights* each month, and have been treated to a wide spectrum of today's best jazz, ranging from Afro-Cuban fusion to Latin and blues rhythms. A selection of authentic tapas, sparkling water, sangria, wine, and beer combined with the sounds of hot jazz and the cool blue, "otherworldly" glow of one of New York's boldest architectural treasures, makes *Starry Nights* one of the city's most popular attractions.

WBGO 88.3 FM serves the New York/New Jersey metropolitan area with straight-ahead jazz, blues, and award-winning news and public affairs programming. Non-commercial WBGO is supported by over 14,000 members and has 400,000 weekly listeners. WBGO also streams its broadcast signal to audiences worldwide at www.wbgo.org. It was named Jazz Station of the Year for 2001 by the *Gavin Report* and also is the recipient of the Blues Foundation's Keeping the Blues Alive Award for Achievement in Non-Commercial Radio.

Media sponsorship for Starry Nights *is provided by CenterCare Health Plan.*

MUSEUM EVENTS

EXHIBITIONS

Vietnam: Journeys of Body, Mind & Spirit

Through January 4, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.


C. CHESEK/AMNH

Vietnamese clay toys depicting zodiac symbols

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.

Biodiversity of Vietnam

Through January 4, 2004
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

The First Europeans: Treasures from the Hills of Atapuerca

Through April 13
Gallery 3, third floor
The mysteries of ancient humans in western Europe are revealed through exquisitely preserved hominid and animal fossils found in the hills of Atapuerca in northern Spain.

Co-organized by the American Museum of Natural History and Junta de Castilla y León.

Einstein

Through August 10, 2003
Gallery 4, fourth floor
This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

The Butterfly Conservatory

Through May 26, 2003
More than 500 live butterflies fly freely in an enclosed tropical habitat.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.*

Experience the sights and sounds of a bustling

Vietnamese Marketplace

at the Museum, throughout the run of the *Vietnam* exhibition. Sample traditional foods and take home a one-of-a-kind handicraft.

77TH STREET LOBBY, FIRST FLOOR

FILMS

A Dream in Hanoi

(In Vietnamese and English with English subtitles)
Tuesday, 4/1, 7:00 p.m.
Two theater companies, one American and one Vietnamese, work together to stage the first performance in Vietnam of *A Midsummer Night's Dream.*

The Season of Guavas

(In Vietnamese with English subtitles)
Thursday, 4/10, 7:00 p.m.
Since falling from a guava tree as a youth, Hoa, now in his fifties, has been trapped in his childhood memories. His obsession with returning to his childhood home leads to a series of unforeseen events.

Chac

(In Vietnamese and English with English subtitles)
Saturday, 4/19, 2:00 p.m.
The director embarks on an emotional and physical journey to discover what caused her mother to flee Vietnam with an American man.

PERFORMANCES

Creativity in Moschen

Saturday, 4/5, 8:00 p.m.
Juggler Michael Moschen brings his innovative object manipulation to the Museum.

Spring Essence: Poetry and Preservation

Sunday, 4/13, 2:00 p.m.
Selected poems from the 18th-century *Spring Essence* sung in the original Vietnamese, and read in English.

When You're Old Enough

Saturday, 4/26, 4:00 p.m.
A dance-theater work in which a young Vietnamese American woman searches for an identity.

LECTURES

The Genomic Revolution: Unveiling the Unity of Life
Tuesday, 4/1, 7:00 p.m.
A discussion about the scientific, social, and ethical implications of the Human Genome Project.

Science and Society: Academic Freedom vs. National Security
Wednesday, 4/2, 7:00–8:30 p.m.
A panel discussion on the topic of intellectual freedoms versus national security concerns.

Krakatoa: The Day the World Exploded: August 27, 1883
Thursday, 4/10, 7:00 p.m.
Simon Winchester discusses his latest book.

World Monument Preservation in Hue, Vietnam
Wednesday, 4/23, 7:00 p.m.
With Minja Yang, Deputy Director of the World Heritage Centre, UNESCO.

Operation Babylift: The Adoptee Experience
Saturday, 4/26, 2:00 p.m.
Roundtable discussion with Vietnamese who were adopted by American families in 1975.

Land Mines: The Legacy of War
Wednesday, 4/30, 7:00 p.m.
Activists and advocates discuss international education and community assistance initiatives.

GUIDED WALKS

Spring Bird Walks in Central Park
Eight-week sessions begin 4/1, 2 & 3

KIDS AND FAMILY

Vietnamese Woodblock Prints
Sunday, 4/6, 11:00 a.m. or 3:00 p.m.

Printmaking a Hand-Book Necklace
Sunday, 4/6, 1:00 p.m.

Mummies
Sunday, 4/13, 10:30 a.m.–1:30 p.m.

Undersea Fossils
Sunday, 4/27, 10:30 a.m.–1:30 p.m.

Origami Birds
Sunday, 4/27, 10:30 a.m.–1:30 p.m.

The Magic of Science
Sunday, 4/27, 11:30 a.m.–12:30 p.m.

HAYDEN PLANETARIUM PROGRAMS

Strange Worlds: Radar Encounters with Earth-Approaching Asteroids
Monday, 4/7, 7:30 p.m.
With Steven J. Ostro, Jet Propulsion Laboratory, NASA.

City of Stars
Sunday, 4/13, 12:00–3:00 p.m.
References to the cosmos in New York City, with Neil deGrasse Tyson.

Einstein in Berlin
Monday, 4/14, 7:30 p.m.
Tom Levenson discusses his book on Einstein's years in Berlin.

2003 Isaac Asimov Memorial Panel Debate
The Big Bang
Tuesday, 4/22, 7:30 p.m.
The world's leading cosmologists debate how the universe was born.

Celestial Highlights
Tuesday, 4/29, 6:30–7:30 p.m.
A view of May's night sky.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

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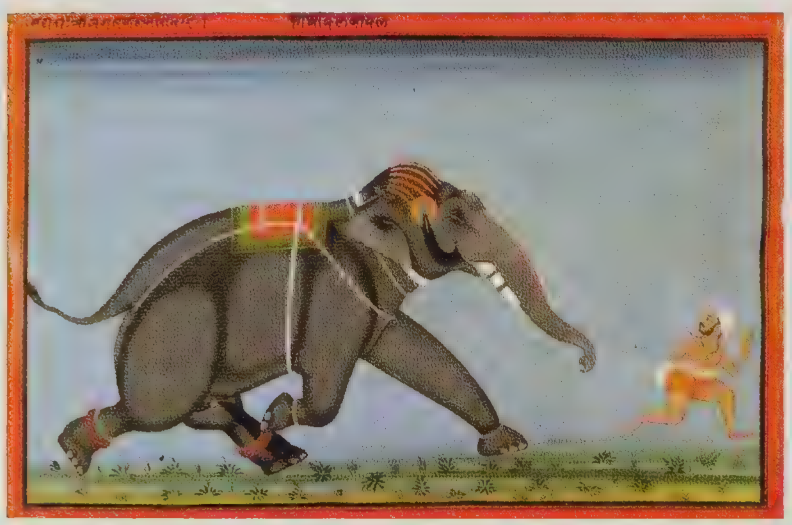
For further information call 212-769-5606 or visit www.amnh.org.

Both a God and a Rogue

By Ravi Corea

I feel a sense of great loss at the sight of a dead elephant. Its colossal size, thick eyelashes, wrinkled skin, long prehensile trunk, and huge calloused footpads evince an animal of magnificent proportions. On a deeper level, what also come to mind are the things I've learned since my childhood in Sri Lanka—the myths, folklore, and all the fantasies of supernatural powers attributed to elephants. The stories form an integral part of the culture in my country.

I still remember the first time I saw an elephant. It was a huge male, with sweeping white tusks. I was about three years old. I thought the elephant never ended! He took over my entire visual world.



The royal elephant Dal Badal chasing his attendant, Mewar, Rajasthan, India, c. 1750

According to an ancient Sri Lankan belief, if you creep under an elephant's belly, you will be safe from *graha dosha* (bad planetary effects) and *deva dosha* (the evil eye), and you will drive away your fears. With a sense of wild adventure and intense excitement—and urged on by my nanny—I crouched down and crawled under its seemingly infinite mass. I will never forget how it felt: as though I were crawling forever. Only when you are underneath an elephant can you appreciate its size.

Elephas maximus has been domesticated in south Asia for more than 4,000 years, and from time immemorial the elephant-headed Lord Ganesha has occupied a place in the Hindu pantheon. Both Hindus and Buddhists revere the god: Buddhists know him as Ganapathi and pray to him for wisdom; Hindus invoke the blessings of Ganesha at the beginning of all enterprises.

Today the elephant in Asia is at a crossroads. Fewer than 50,000 remain. (Within a far more restricted range, their African cousins number more than 600,000.) In Sri Lanka, as elsewhere, the elephant's mythical and worldly roles are in conflict. Every year for the past decade, between 100 and 150 elephants have been killed in their increasingly intense competition with people for land. Still revered as a god, the elephant has now become a rogue that steals crops, destroys property, and plunders villages in the dark of night, killing farmers and settlers.

Two years ago in a village in the island's North Central province, a young woman named Sudu Menika went to her temple to pray. There she made a special offering to Ganapathi on behalf of her oldest son. Later that night a call went out that an elephant was on the rampage. Sudu Menika was running for shelter, her second-born son in her arms, when the elephant appeared and rushed at her from the side, striking her with its trunk. The infant landed on a heap of straw, which probably saved his life. Sadly, though, his mother died a short time later. In one night she had both prayed to the elephant god and met her death from its earthly counterpart.

The conflict between people and elephants is most often measured by such physical loss, but there is also an emotional price to pay. The elephant's godly status is deeply ingrained in the local culture and religion, yet, to protect themselves, the Sri Lankans persecute the animal. That internal conflict takes its toll: whenever a marauding elephant is killed, the entire village gathers to pay its solemn respects. Most of the mourners are seeing a wild elephant in the light of day for the first time, an animal that lived and breathed, but that they also worship as a god. In our relentless push for development we have displaced this living symbol of the divine and turned it into a rogue.

Ravi Corea studies at Columbia University's Environmental Research Center, and is the president of the Sri Lanka Wildlife Conservation Society (www.SLWCS.org).

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Ever since the first human went into a dark cave and built a fire, people have realized the importance of proper indoor lighting. Unfortunately, since Edison invented the light bulb, lighting technology has remained relatively prehistoric. Modern light fixtures do little to combat many symptoms of improper lighting, such as eye strain, dryness or burning. As more and more of us spend longer hours in front of a computer monitor, the results are compounded. And the effects of indoor lighting are not necessarily limited to physical well being. Many people believe that the quantity and quality of light can play a part in one's mood and work performance. Now VERILUX®, a leader in healthy lighting since 1956 has developed a better way to bring the positive benefits of natural sunlight indoors.

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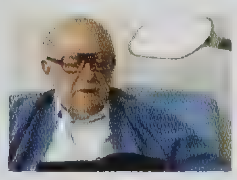
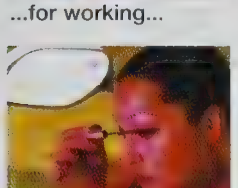


...for reading...

...for working...



...and when you need a good source of light for close-up tasks.

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—Karen R. CA

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—Jan L. GA

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—Kathy N. CA

It is really nice and eliminates the glare!
—Nita P. CA

It is a nice sunny product for a windowless office.
—Edith L. NJ

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NATURAL HISTORY

5/03

THE WATER PLANET

Even for Drs. Schwartz and Kalet, two people familiar with the fragile biology of humans, the inevitable can be an unpleasant subject. Nevertheless, they know the life cycle can be hard to predict and the unthinkable is always a possibility. And they wanted to make sure the ones closest to them would be provided for. That's why they added life insurance from TIAA (part of the TIAA-CREF group) to their portfolio. Then they got back to thinking about the *life* part instead of the *insurance* part.
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Drs. Schwartz and Kalet were issued life insurance from Teachers Insurance and Annuity Association (TIAA) in 1990. TIAA-CREF Life Insurance Company, New York, NY, and TIAA issue life insurance policies. TIAA-CREF Individual and Institutional Services, Inc., and Teachers Personal Investors Services, Inc., distribute securities products. This is a paid endorsement. ©2002 Teachers Insurance and Annuity Association–College Retirement Equities Fund (TIAA-CREF), New York, NY.
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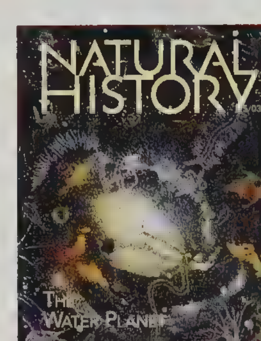
NATURAL HISTORY

MAY 2003 VOLUME 112 NUMBER 4

FEATURES

THE WATER PLANET



COVER
Alexis Rockman, *Biosphere: Hydrographer's Canyon*, 1994

STORY BEGINS ON PAGE 40

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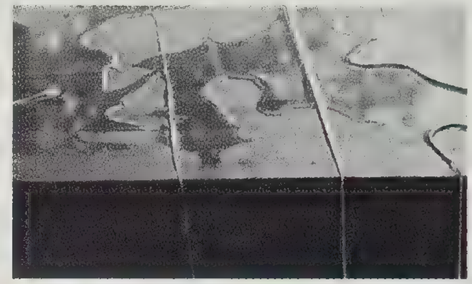
DEPARTMENTS

THE WATER PLANET



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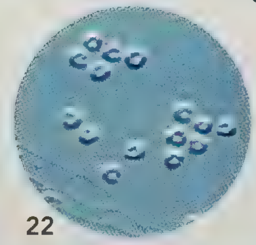

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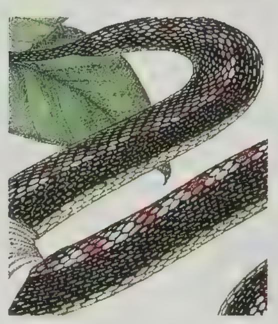

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PICTURE CREDITS: Page 12

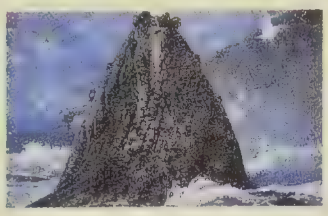

GMT-MASTER II
SUPERLATIVE CHRONOMETER
SWISS MADE

Bubble Feast

Photograph by Duncan Murrell

THE NATURAL MOMENT

◄ *See preceding pages*



To say that baleen whales feed by passively filtering krill is almost to insult the mammals' truly sophisticated behavior. Humpback whales *(Megaptera novaeangliae)* are known to hunt in remarkably cooperative and cohesive groups. Pictured here, in an Alaskan inlet, is a humpback mid-maneuver in a feeding mode known as bubble-netting. The giant's grooved throat, studded with sensory nodules and acorn barnacles, bulges with Pacific herring—an elusive and fast-moving species compared to krill—caught by coordinated efforts.

At a depth that depends on the number of feeding whales and the quantity, location, and kind of prey, one whale begins the hunt by blowing massive air bubbles. Another member of the pod (often six or seven whales in all) sounds a deep, resonant call that signals a move to drive the school of fish upward, trapping them at the surface in a roiling "net" of bubbles. As sonar studies have shown, each whale probably takes a particular position in the herding operation of every hunt.

For decades photographer Duncan Murrell has observed the humpback whales by paddling unobtrusively alongside the pods in his kayak. The whale in the photograph, Murrell says, "launched from the water," catching him slightly off-guard—a minor jolt for the photographer, who, that very same morning, had been sprayed with blowhole oil, slapped by a monstrous flipper, and momentarily beached on the body of a whale. —*Erin Espelie*

UP FRONT

Thinking Blue

One of the most astonishing discoveries a visitor can make during a first love affair with New York City is "the whale," a ninety-four-foot life-size model of a blue whale that has swum overhead since 1969 in the vast Hall of Ocean Life, at the American Museum of Natural History. For sixteen months, though, the whale has been swimming in the dark—getting a thorough cleaning and anatomical updating as the entire exhibition gets a face-lift. This month, on May 17, the whale resurfaces into public space.

But even without such a motivating occasion as the return of the whale, you don't have to be a mariner to think about the Earth as the water planet. All you have to do is gaze at one of those glorious images of our planet that NASA has made from space. What biologists see, though, when they look at the blue of our planet is more like sap or film than simple liquid, a soupy goo so thick with suspended, replicating cells that it constitutes a kind of living plenum, a continuous fullness of life.

Edward F. DeLong brings the story of microscopic sea life up to date in his article, "A Plenitude of Ocean Life" (page 40). DeLong recounts how the so-called Archaea, whose identity as one of the three great branches of life went unrecognized until a few decades ago, are now known to comprise between 20 and 30 percent of all oceanic microbial cells. Previously unknown genera of bacteria-size "picoplanktonic life," DeLong reports, reach densities greater than 100,000 cells per milliliter of seawater. One such genus, *Prochlorococcus,* constitutes half of the total chlorophyll-based biomass in the open ocean.

There are several themes here worth exploring beyond the sea. One is the affinity of life with water of any kind. The quest for freshwater has driven great architecture (see "Temples for Water," by Morna Livingston, page 52), and it is liable to drive terrible future wars (see "Hydro Dynamics," by Sandra Postel, page 60).

Life is also drawn to other forms of life. Somewhere in a rainforest, inside a rotting log, lives a colony of termites. Inside the termites live protists and bacteria that digest wood cellulose. Yet the colony not only forages; it also farms. Within the log grow mushrooms, apparently cultivated by the termites for food. Throughout the example run themes of mutual dependence, cooperation among species, habitat made from the tissues of other organisms.

The great champion of this point of view is Lynn Margulis, who joins us in this issue with her thrilling, infectious enthusiasm for the world of the very small (see "Mycological Maestros," by Jessie Gunnard, Andrew Wier, and Margulis, page 22). Margulis has inspired her students for many years with her supreme confidence in their own powers of scientific observation. She firmly believes that armies of biologists must still be trained to bring back to science the secrets of the living Earth. At *Natural History,* we are honored to share her niche, and to bring her words to you. —PETER BROWN

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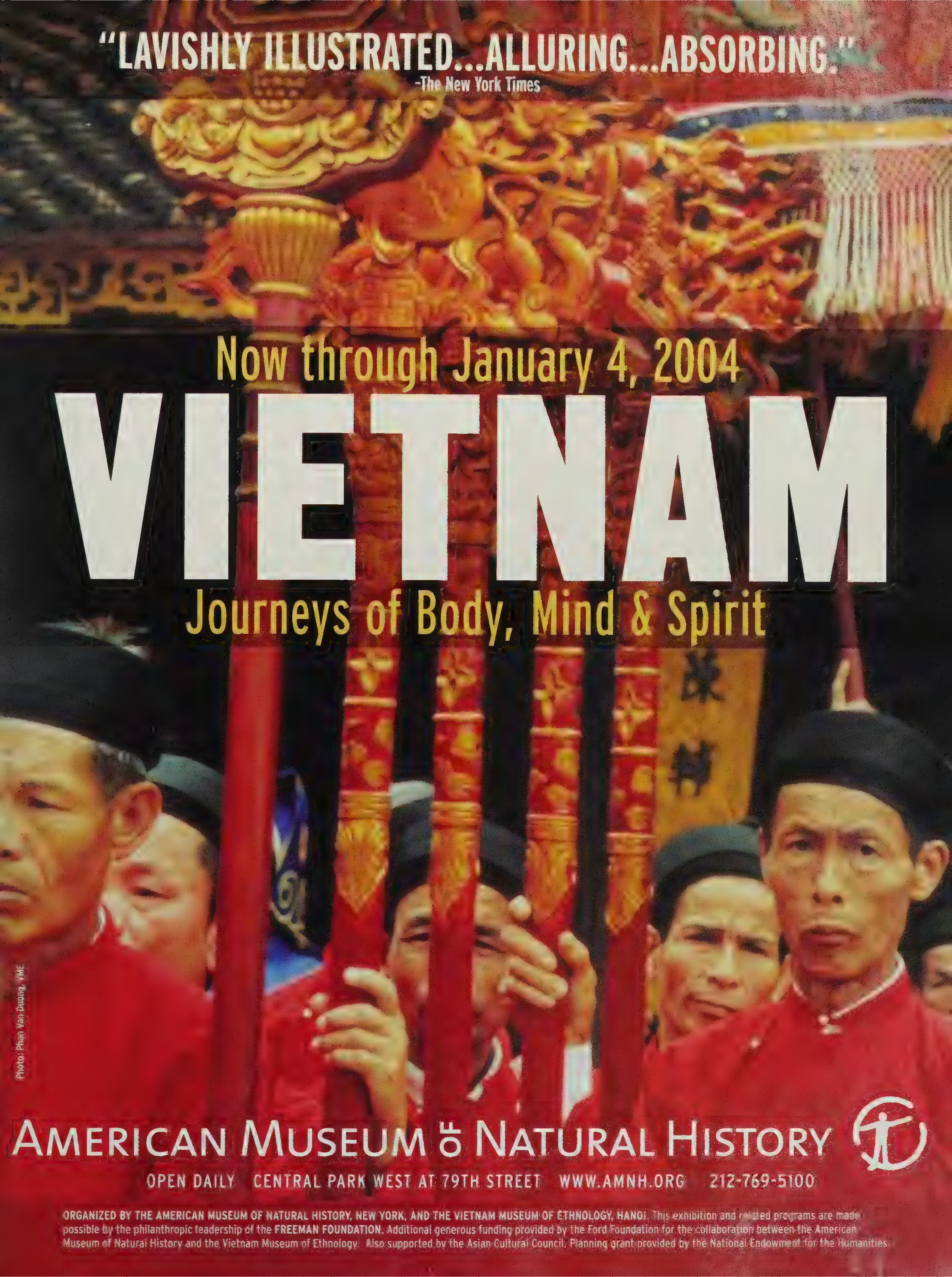
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Rights and Wrongs

In his "Universe" column ["Naming Rights," 2/03], Neil deGrasse Tyson acknowledges that slavery in the United States affected scientific endeavors. But he ignores the fact that many of the Islamic nations whose history he lauds also had questionable records on human rights. He refers to Christian zealots but makes no mention of zealots of any other kind—among them the Islamist zealots who are responsible for the decline in the once-great scientific communities of the Islamic world.

Dawn Bailey
Fayetteville, Arkansas

NEIL DEGRASSE TYSON REPLIES: Dawn Bailey's critique is entirely within reason, but I didn't have space to include each culture's full negative history. In my essay I made two assumptions, both of which derive largely from the way history has been presented in school textbooks in the West: (1) many (if not most) readers are unfamiliar with the Islamic world of the eighth through eleventh centuries, and (2) every reader is familiar with the technological dominance of Europe and the United States.

So to mention that Islam was advanced while Europe was in squalor is more enlightening to the reader than to say that Islam was in squalor while Europe was advanced. And to say that the U.S. participation in the Industrial Revolution was delayed, in part, because of slavery is more enlightening than to say that Islam has zealots today.

The Shadow Knows

Neil deGrasse Tyson's article on low-tech science ["Stick-in-the-Mud Science," 3/03] reminded me of my career in educational television nearly half a century ago. *Sputnik 1* had begun to orbit, and suddenly Americans noticed that their schools were not teaching much science. Auburn University decided to televise a class in science for the upper elementary grades; I was a physical chemist, but I could talk to kids, so they picked me. Because one bake sale could buy a couple of television sets for a school, I soon had thousands of students.

Besides doing four half-hour broadcasts a week, I made a lot of school visits. Among the simple experiments I carried in my purse was the "sun tracker," which included an empty thread spool, a straight pin, and a pencil stub with a bit of eraser remaining. To assemble it, you put the pencil stub into the hole of the spool and stuck the pin straight up in the middle of the eraser. All the class had to provide was a sheet of white paper and a window into which the sun shone at noon.

If you set the spool on the paper on the windowsill, and made a dot on the paper every day at noon where the shadow of the pinhead fell on the paper, you could plot a pretty good analemma in the course of a year.

Charlotte R. Ward
Auburn, Alabama

Φ

Two intriguing properties of phi (ϕ), the golden ratio, did not make it into Mario Livio's article "The Golden Number" [3/03]. Elementary algebra shows that subtracting one from phi yields its reciprocal (1/phi); and the fact that phi + 1 is equal to the square of phi yields, by simple addition, the further fact that the sum of phi and its reciprocal is equal to two times phi.

It is small wonder that many of the ancient Greeks regarded geometry as a form of magic.

Maxwell Manes
Brooksville, Florida

Curiouser and Curiouser

In his book review "The Curious Energy of the Void" [2/03], Donald Goldsmith states: "As the universe expands, . . . more space continuously comes into being, and so the total amount of dark energy also increases proportionately." In effect, energy is continuously created—an assertion that, for me, is quite counterintuitive.

Later he writes, "The amount of radiation generated by the universe in the earliest years of its expansion varies in different directions in space." But that seems to contradict a reference to "the pervasiveness and uniformity of the radiation throughout the universe" made elsewhere in the same issue ("At the Museum").

Howard J. Naftzger
Kensington, California

DONALD GOLDSMITH REPLIES: Howard Naftzger raises two excellent and appropriate questions. He is right to find it counterintuitive that new energy appears as space expands—not to mention that it's a violation of just about every physical rule in the books. That is one reason (and there are more!) conservative cosmologists have been slow to accept the existence of dark energy.

Nevertheless, new results from the Wilkinson Microwave Anisotropy Probe (WMAP) satellite seem to confirm almost beyond a doubt that space does teem with dark energy. Cosmologists like to call the new energy "the ultimate free lunch." If it's any help, according to our conception of physics, the universe as a whole does not have to obey the same rules as a closed, localized system does.

As for the uniformity of the cosmic background radiation, there are two salient facts. First, the background *is* amazingly uniform, arriving in the same amounts and with the same spectrum from all directions. Second, astronomers have now detected extremely small deviations from uniformity—the so-called anisotropies of the cosmic background radiation [*see "Sharper Focus," by Charles Liu, page 70*]. The anisotropies, small as they are, carry large amounts of information about the universe as it existed when the radiation was first set loose, a few hundred thousand years after the big bang.

By measuring the anisotropies on various an-

gular scales, cosmologists can (amazingly) hope to determine the curvature of the universe, which amounts to determining the total quantity of all kinds of matter and energy. My book *The Runaway Universe* deals to some degree with these not-so-simple subjects.

Cattle Call

Daniel G. Bradley concludes that British aurochs did not interbreed with early domestic cattle ["Genetic Hoofprints," 2/03]. But that assertion overlooks that fact that (especially early on) domestication is a social as well as a biological process. Calves born to tame mothers living with humans would either prove tractable and so be kept to breed, or intractable and so escape or be eaten, outcomes that are genetically equivalent. Tractable calves born to wild mothers would only be captured and tamed with some effort; because the early inhabitants of Britain already had domestic cattle, few farmers would have bothered.

In short, a one-way "filter" would be applied to nuclear genes, which Mr. Bradley's work on mitochondrial DNA could not detect. Wild aurochs bulls breeding with domestic cows would contribute nuclear genes, but no mitochondrial genes, to early cattle; as long as such domestic cows gave birth and raised their calves near humans, their calves would likely join the domestic herd.

James J. Moore
University of California, San Diego
La Jolla, California

DANIEL BRADLEY REPLIES: James Moore highlights an important limitation that applies to all genetic evidence based on one marker system: different genes can represent different strands within the history of a population and thus tell different histories. In fact, cattle studies present one of the best examples of uncoupling of maternal and other ancestral strands. The massive influx of *Bos indicus* genes into African cattle seems to have left no maternal legacy: the mitochondrial genes in African cattle seem to have remained *B. taurus.*

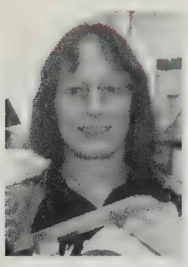
Thus I agree that the study of mitochondrial variation alone cannot eliminate the possibility that ephemeral encounters introduced nuclear DNA from British aurochs into the domestic gene pool. Studies of other marker systems, particularly the Y chromosome, will clarify that question. In fact, however, our preliminary data from modern British cattle with Y markers have not revealed any traces of divergent chromosomes that might indicate substantial wild male input.

Natural History*'s e-mail address is nhmag@amnh.org.*

CONTRIBUTORS

DUNCAN MURRELL ("The Natural Moment," page 6) is a naturalist who has been kayaking with Alaskan humpback whales for more than twenty-five years. He will be exploring the marine life around the islands of Sri Lanka and Madagascar in the coming year. His photograph of a bubble-feeding humpback whale was made in Tenakee Inlet of Chichagof Island, Alaska.

As a five-year-old tyke wading in the northern California surf, **EDWARD F. DELONG** ("A Plenitude of Ocean Life," page 40) was knocked down by a large wave and dragged a little way out to sea. He has had a serious interest in—and respect for—the ocean ever since. A senior scientist at the Monterey Bay Aquarium Research Institute in California, DeLong studies the smallest marine microorganisms known, a category called picoplankton. His current research topics include methane cycling in the deep ocean and the application of genomics to the study of microbial communities. DeLong enjoys swimming, hiking, scuba diving, and cross-country skiing, pastimes he puts to good use in his work. Cross-country skiing, for instance, enabled him to crisscross Antarctic ice packs when he set out to collect seawater samples by drilling holes through ice two meters thick.



After receiving her license to teach piano in Germany, **INGRID FRITSCH** ("A Yen for the Traditional," page 48) went on to earn a doctorate in ethnomusicology (with a focus on the Japanese bamboo flute) at Cologne University. She has subsequently done extensive fieldwork on the social and religious organization of guilds of blind musicians and shamans in Japan. Currently Fritsch is a professor at the Institute of Japanology in Cologne, Germany. Her article on *chindonya* is just one aspect of her fascination with the itinerant performers and street artists who have characterized Japanese culture for many centuries.

Architectural photographer and historian **MORNA LIVINGSTON** ("Temples for Water," page 52) has lugged two cameras and assorted photographic accessories from northern Tunisia to southern Tuscany to the arid lands of western India. On her journeys she has visited myriad works of architecture, including ancient Roman baths, Renaissance gardens, and the "water buildings" commissioned by Hindu queens and Muslim sultans that are the subjects of her article and photographs in this issue. Livingston is the author of *Steps to Water: The Ancient Stepwells of India* (Princeton Architectural Press, 2002). When not traveling to villages searching for water buildings to study and photograph, Livingston teaches in the School of Architecture and Design at Philadelphia University.

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By Stéphan Reebs

Sperm whales congregating at the surface of the sea

YOU SAY TOMATO, I SAY TOMAHTO Not all members of the same species whistle the same tune. Groups of white-crowned sparrows and killer whales, for instance, may utter different songs or calls on similar occasions. Populations of cetaceans that share a vocalization "dialect" are known as vocal clans.

Now Luke Rendell and Hal Whitehead, both biologists at Dalhousie University in Nova Scotia, Canada, have completed an extensive analysis of the cocktail chatter of thousands of sperm whales, recorded throughout the Pacific and the Caribbean between 1985 and 2000. They identified at least six distinct dialects among the whales—five dialects in the Pacific and one in the Caribbean—some of which extend across thousands of miles and involve thousands of whales.

Sperm whales live in groups of between ten and twenty animals. They communicate through what are called codas—brief series of clicks—distinguished not only by the number of clicks but also by the intervals between the clicks. Some whale groups, for instance, always make five regularly spaced clicks, whereas others always make a longer pause before emitting the final click in the coda.

While moving through the seas, groups of sperm whales gather for days at a time with their counterparts; although groups from different vocal clans may occupy the same general area, each group mingles only with others that click the same dialect. And those dialects are probably learned—the result of a cultural process that, in this case, is literally oceanic in scale. ("Vocal clans in sperm whales *[Physeter macrocephalus]*," *Proceedings of the Royal Society of London* B **270**: 225–31, February 7, 2003)

FOLD THREE TIMES AND DRINK One of the world's most notorious waterborne diseases is cholera, caused by the bacterium *Vibrio cholerae*. For decades bacteriologists have known that the organism lives in close association with zooplankton, particularly the minute crustaceans known as copepods. A single copepod, in fact, can harbor as many as 10,000 *V. cholerae*—just about enough to trigger the disease. Not surprisingly, cholera outbreaks often follow zooplankton blooms.

In rural Bangladesh, where cholera is endemic, villagers drink untreated surface water. Systematic chemical treatment is often too expensive, many wells are heavily contaminated with arsenic, and boiling the water is often difficult and costly. Women (traditionally the water carriers for their households) do filter drinking water through a piece of old cotton sari cloth, but only to remove coarse debris. So the cell biologist Rita R. Colwell, director of the National Science Foundation, and her colleagues suggested that the cloth simply be folded into four to eight thicknesses. (The cloth was also to be washed and sun-dried after each filtration.) That single act, they contended, would drastically reduce the incidence of cholera, because the multiple layers of cloth would provide a mesh fine enough to remove all the zooplankton.

Collecting water in rural Bangladesh

Enlisting the participation of 133,000 people from sixty-five Bangladeshi villages, Colwell and her team recently completed a three-year study of the method. They found not only an impressive rate of compliance—fewer than 1 percent of the households didn't follow instructions—but also a 48 percent reduction in the incidence of the disease, to 0.65 cases a year per thousand people. ("Reduction of cholera in Bangladeshi villages by simple filtration," *Proceedings of the National Academy of Sciences* **100**:1051–55, February 4, 2003)

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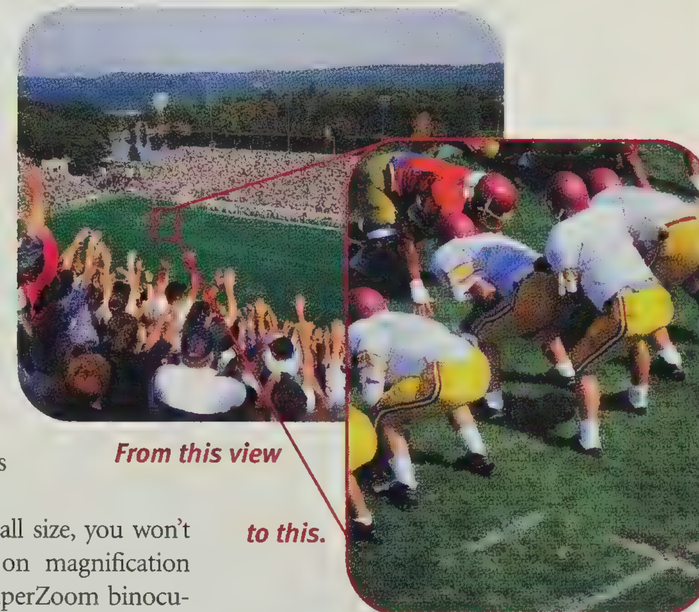

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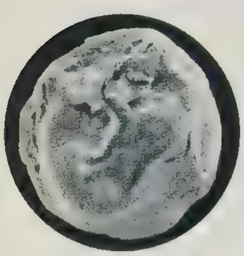
NOT GUILTY About 11,500 years ago in North America, people started using fluted stone points for hunting. Archaeologists have called those people "Clovis," after the town in New Mexico where the characteristic stone points were first discovered. That same epoch, 11,500 years ago, appears to coincide with the disappearance of numerous large mammals from North America, including the giant beaver, the mastodon, and various ground sloths. Some people have argued that Clovis hunters were responsible for the extinctions, but the claim has now been disputed by two archaeologists, Donald K. Grayson of the University of Washington in Seattle and David J. Meltzer of Southern Methodist University in Dallas.

An array of Clovis points

The two examined published evidence for seventy-six sites where the association between Clovis people and large mammals was supposedly prominent. Only fourteen of the sites contained secure evidence of killing or butchering, such as impact-fractured projectile points within the animal remains, cut marks on bones, or skeletal dismemberment—and only mammoths or mastodons were present at those sites. Not one site yielded clear evidence that Clovis people had actively hunted any of the other thirty-three mammalian genera that became extinct at about the same time. And although tools made from the bones of large mammals were found at some sites, their presence doesn't prove the animals were hunted; the tools could have been fashioned from the skeletons of scavenged animals.

Grayson and Meltzer also point out that the North American extinctions coincide with similar extinctions in Europe and Asia, yet Clovis hunters didn't live there. The archaeologists thus argue that the Clovis hunter should be exonerated as the cause of the North American extinctions. Perhaps, they suggest, a widespread environmental event such as climate change was responsible. ("Clovis hunting and large mammal extinction: A critical review of the evidence," *Journal of World Prehistory* **16:**313–59, December 2002)



Artificially mineralized egg

EXPERIMENT OF THE MONTH Amid all the fanfare that has accompanied recent discoveries of fossilized Precambrian invertebrate eggs found in China and elsewhere, a few grumbles of disbelief have been heard. After all, invertebrate eggs are made of soft tissue, so shouldn't they decompose long before mineralization begins?

The answer is: not necessarily. Derek Martin, Derek E.G. Briggs, and R. John Parkes, all of the University of Bristol in England, dropped lobster eggs into vials containing seawater and natural sediments, then sealed the vials and incubated them at 59 degrees F. After three weeks the intact eggs were coated with a thin layer of calcium carbonate, which stabilized their shape. Mineralization had begun.

The process depends on two key factors: the lack of oxygen (a gas that speeds decomposition) and the presence of anaerobic bacteria (whose metabolic activity helps make minerals available). Paleontologists had previously thought that invertebrate eggs couldn't be fossilized unless the exoskeleton of a relatively large animal (the mother, for example) lay close enough to serve as a ready source of calcium or phosphorus for the compounds that would constitute the fossil. But the Bristol experiment suggests that orphaned eggs, including those produced by small, soft organisms, could still have become naturally fossilized. ("Experimental mineralization of invertebrate eggs and the preservation of Neoproterozoic embryos," *Geology* **31:**39–42, January 2003)

TRAVELING LIGHT Why do some plant immigrants spread so widely and destructively in their adopted lands, yet remain relatively innocuous back home? Presumably the new host country lacks some of the disease-causing fungi and viruses that afflict the plant in its native land. Hence, as long as the plant can resist the new pathogens it encounters in its adoptive home, it will become . . . a weed.

Charles E. Mitchell and Alison G. Power, both biologists at Cornell University, delved deep into the databases of the U.S. Department of Agriculture and identified 473 plant species introduced (whether by accident or on purpose) into the United States from Europe. They found that, on average, 84 percent fewer fungal species and 24 percent fewer viral species infected the plants in the U.S. than in Europe. And for individual species, the lighter the burden of pathogens, the more states officially listed the plant as a "noxious weed." The few pathogens still afflicting the expatriate plants were an even mix of introduced and indigenous ones. Thus, both their escape from old pathogens and their resistance to new ones contributed to the invaders' success. ("Release of invasive plants from fungal and viral pathogens," *Nature* **421:**625–27, February 6, 2003)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

Dust to Dust

In the darkest regions of the Milky Way are vast interstellar clouds harboring the remains of dead stars and the nurseries for new ones.

By Neil deGrasse Tyson

A casual look at the Milky Way on a dark, clear night reveals a cloudy band of light-and-dark splotches extending from horizon to horizon. With simple binoculars or a backyard telescope, the dark and boring areas of the Milky Way look like, well, dark and boring areas. But the bright areas resolve into countless stars and nebulae.

In a small book titled *Sidereus Nuncius* (The Starry Messenger), published in Venice in 1610, Galileo gives an account of the heavens as seen through a telescope, including the first-ever scientific explanation of the Milky Way's patches of light. Referring to his yet-to-be-named instrument as a "spyglass," he is so excited he can barely contain himself:

> The Milky Way itself, . . . with the aid of the spyglass, may be observed so well that all the disputes that for so many generations have vexed philosophers are destroyed by visible certainty, and we are liberated from wordy arguments. For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters. To whatever region of it you direct your spyglass, an immense number of stars immediately offer themselves to view.

Surely to Galileo and his contemporaries, the "innumerable stars" were where the action was. Why would anyone care about the dark areas, where stars were presumably absent?

Three centuries would pass before anybody figured out that the dark patches are thick, gigantic clouds of gas and dust, which obscure more distant star fields. Among the first astronomers to address the problem was an American, George Cary Comstock, who wondered why faraway stars are much dimmer than their distance alone would indicate. Following up on Comstock's observations, the Dutch astronomer Jacobus Cornelius Kapteyn named the culprit in 1909, when he presented evidence that clouds of "meteoric dust" in the space between the stars not only absorb the overall light of stars, but do so unevenly across the rainbow of colors in a star's spectrum. Specifically, the clouds attenuate blue light more than red, making the Milky Way's faraway stars look dimmer and, on average, redder than the ones nearby.

> ***If no one knew that stars exist, there would be plenty of reasons to think they should never form.***

Ordinary hydrogen and helium, the principal constituents of cosmic gas clouds, don't redden light. But large molecules do—particularly the ones that include atoms of carbon or silicon. And when the aggregations of such atoms and molecules get big enough, we call them dust.

Most people are familiar with dust of the household variety, though few know that, in a closed home, it is made up mostly of dead, sloughed-off human skin cells—plus pet dander, if you have a live-in mammal. Last I checked, nobody's epidermis has gotten into the interstellar dust. But the cosmic clouds do include a remarkable ensemble of complex molecules that emit microwaves, and dust that emits primarily in the infrared part of the spectrum. Not until the last third of the twentieth century, however, did the astrophysicist's tool kit enable us to observe the powerful emissions and chemical richness of the stuff between the stars.

Interstellar clouds are intriguing for yet another reason. Deep within them, through the effects of their internal gravity, the dust and gas become thick enough to condense into clumps of matter. If conditions are just right, those clumps can form larger and larger clumps, and eventually full-fledged stars. In other words, those giant clouds are stellar nurseries.

Gas clouds in the Milky Way are not always capable of starbirth. More often than not, even after a cloud forms, it is confused about what to do next. Actually, we astrophysicists are the confused ones. We know the cloud is trying to collapse under its own weight and make one or more stars. But the cloud's rotation, as well as turbulent motion within it, acts against collapse. So, too, does ordinary gas pressure. Galactic magnetic fields also fight collapse: they penetrate the cloud and, latching onto any charged particles roaming within, restrict how the cloud can respond to its own gravity. What's scary is that if no one knew in advance that stars exist, frontline re-

search could offer plenty of convincing reasons stars should never form.

Like the Milky Way's several hundred billion stars, gas clouds orbit the center of the galaxy. On the galactic scale, stars are minute specks, a few light-seconds across, in a vast ocean of space. In contrast, some gas clouds are huge, spanning hundreds of light-years. Such clouds can be as massive as several million suns. And as they lumber through the galaxy, they often collide with each other, entangling their innards. Sometimes, depending on their relative speeds and their angles of impact, the clouds stick together like hot marshmallows; other times, adding injury to insult, they rip each other apart.

If a gas cloud's temperature drops below about a thousand degrees Kelvin, conditions become favorable for forming complex molecules and dust. Below a hundred, conditions become ideal. Those chemical transitions have consequences for everybody. Dust grains, which are made up of billions of atoms, absorb visible light—strongly attenuating the brightness of stars behind them. The dust then re-emits the energy as infrared radiation, which freely escapes the cloud.

Whatever the forces that make a cloud colder and denser, they may eventually lead to the cloud's gravitational collapse. And that, in turn, leads to the birth of stars. Nature thus poses a paradoxical precondition. To create a star —that is, to heat matter hot enough for it to undergo thermonuclear fusion—the temperature inside the star's parent cloud must first be as cold as possible.

At this point in the life of a cloud, astrophysicists can only gesticulate to show what happens next. Theorists and computer modelers face the challenge of incorporating all the known laws of physics and chemistry into their supercomputer models before they can even think about tracking the turbulent motions of large, massive clouds. A further challenge is the humbling fact that the original cloud is billions of times wider and a hundred sextillion (100×10^{21}) times less dense than the star the models are trying to simulate. And the laws of physics that matter at one size or on one timescale are not necessarily the right things to worry about on another.

Neil Folberg, *Sagittarius*, 2000

Nevertheless, astrophysicists can safely assert that in the deepest, darkest, densest regions of an interstellar cloud, with temperatures around 10 degrees above absolute zero, pockets of gas finally collapse, converting their gravitational energy into heat. The temperature within each collapsing pocket—soon to become the core of a newborn star—rises rapidly, breaking nearby dust grains into their constituent atoms. Eventually, if the collapsing gas heats up to 10 million degrees, the positively charged protons (which are just naked hydrogen atoms that have been stripped of their electrons) move so fast that their natural repulsion no longer keeps them apart. In fact, those protons get close enough to be pulled together by a short-range, attractive, monstrously strong nuclear force (whose technical name is "strong nuclear force").

When protons bond with each other under the influence of that force, the process is known as thermonuclear fusion. The by-product of fusion is the

element helium, whose mass is less than the sum of its parts. The missing mass becomes boatloads of energy, as described by Einstein's famous equation $E=mc^2$, where E is energy, m is mass, and c is the speed of light. As the energy moves outward, the gas becomes self-luminous. And though this crucible remains enclosed, womblike, within the greater cloud, its glow nonetheless announces to the rest of the Milky Way that a star is born.

Astrophysicists know that stars come in a wide range of masses: from a mere tenth to nearly a hundred times that of our Sun. Each giant gas cloud holds a multitude of cold pockets, all of which form at about the same time and each of which gives birth to a star. For every high-mass star that's born, a thousand low-mass stars emerge. But only about 1 percent of all the gas in the original cloud participates in starbirth, and that presents a classic challenge: How and why does the tail (the stars) wag the dog (the cloud)?

The mass limit on the low end is easy to determine. Below about a tenth of the Sun's mass, the pocket of collapsing gas does not have enough gravitational energy to bring its core temperature up to the requisite 10 million degrees. A star is not born.

What forms instead is a "brown dwarf" [*see "When a Star Is Not Born," March 1996*]. With no energy source of its own, a brown dwarf just gets progressively dimmer with time, living off what little heat it was able to generate from its original collapse. With such a feeble luminosity, a brown dwarf is supremely difficult to detect, requiring methods similar to the ones used to discover planets outside the solar system. In fact, only in recent years have enough brown dwarfs been discovered in sky surveys to merit sorting them into categories.

The exact mass limit at the high end isn't well understood, but what astrophysicists do know we can credit to the star's prodigious luminosity. About a hundred times the mass of the Sun seems to be the limit; if any more mass from the parent cloud tries to join the action, it gets pushed away by starlight alone.

So potent is the pressure of intense starlight that the luminosity of just a few high-mass stars can heat up and disperse nearly all the dust and gas from the original cloud. As the cloud dissipates, dozens, if not hundreds, of brand-new stars—siblings of one another, really—are laid bare for the rest of the galaxy to see.

The Great Nebula in Orion—situated below Orion's belt and midway down his sword—is just such a nursery. Within the nebula, thousands of stars are being born, spread among several rich clusters. Four of the most massive stars trace the Orion Trapezium, and they're busy blowing a giant hole in the middle of the cloud from which they formed. New stars are clearly visible in detailed images of the region made by the Hubble Space Telescope, showing many infants swaddled in nascent, protoplanetary disks comprised of dust and other molecules drawn from the original cloud. And within each of those disks a solar system forms.

The highest-mass stars are the brightest and shortest-lived, but they cooked the elements that gave rise to us.

For a while, the cluster of newborn stars stays intact. But eventually, owing to the steady gravitational tugs of enormous passing clouds, the ensemble falls apart, its members scattering into the general pool of stars in the galaxy. The low-mass stars live practically forever—so dim are they, and so meager is their consumption of fuel. The intermediate-mass stars, such as our Sun, sooner or later turn into red giants, swelling a hundredfold in size as they march toward death. In the end, their outermost layers become so tenuously connected to the rest of the star that they drift into space, exposing the spent nuclear fuels that powered their 10-billion-year lives. The gas that returns to space ultimately gets swept up by passing clouds, only to participate in later rounds of star formation.

In spite of the rarity of the highest-mass stars, they hold nearly all the evolutionary cards. They boast the highest luminosity—a million times that of the Sun—and, as a consequence, the shortest lives: only a few million years. The cores are hot enough to cook hydrogen into dozens of heavier elements, starting with helium and proceeding to carbon, nitrogen, oxygen, and so forth, until they get to iron—of all the elements the one whose nucleus has the lowest energy per particle. Any fusion beyond iron will absorb rather than release energy.

With no more nuclear fuel, such stars die spectacular deaths in supernova explosions, making still more elements in their fires and briefly outshining their entire home galaxy. The explosive energy spreads heavy elements across the galaxy, blowing holes in its distribution of gas and enriching nearby clouds with the raw materials to make dust of their own. The blast waves of the supernovas move supersonically through the clouds, compressing the gas and dust, and possibly creating pockets of extremely high density—the preconditions for the formation of stars.

A supernova's greatest gift to the cosmos is to seed clouds with the heavy elements that form planets and protists and people, so that once again, further endowed by the chemical enrichment from an earlier generation of high-mass stars, another star is born.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

Mycological Maestros

In the Ecuadorean rainforest, a "missing link" in the evolution of termite agriculture?

By Jessie Gunnard, Andrew Wier, and Lynn Margulis

From the vantage of our laboratory at the University of Massachusetts in Amherst, the eye can wander over the majestic landscape of the Connecticut River Valley. It is a landscape profoundly shaped by cultivation: field boundaries are marked, the soil is tilled and fertilized, and specially selected crops (strawberries, asparagus, tomatoes, apples) grow in patches and rows. Farming has been carried on full tilt by people somewhere in the world for the past 10,000 years.

Some other animals, too, have moved beyond hunting and gathering. In a shoebox-size plastic bin in our laboratory, termites of the species *Heterotermes tenuis* busy themselves in their home, a log flown in from Ecuador. These termites belong to a family of insects that live in symbiotic collaboration with bacteria and swimming protists: the insects ingest wood and the protists living in their bloated abdomens digest the wood particles, mainly the cellulose; some bacteria change the sugars from cellulose to smaller compounds that pass through the intestinal wall. Other bacteria "fix" nitrogen from the air, making it nutritionally available. *H. tenuis* and other termites that depend on their hindgut crew of microorganisms to nourish themselves with wood belong to a group of insects known by the misleading name "lower termites." They would more accurately be called earlier or older termites.

The banks of the Tiputini River in Ecuador—home to a population of the termites Heterotermes tenuis *that was examined by the authors*

Their collaboration is a pretty neat trick, but it differs greatly from the equally remarkable activities of a more recently evolved branch of termites. The latter group of species is part of a broader classification commonly known as the "higher termites," which are termites that do not depend on hindgut protists to digest their food. Some higher termites thrive, instead, by cultivating monocultures of fungi: they farm mushrooms. How and when that behavior evolved in termites has long been an open question. But we suspect the *H. tenuis* in our plastic bin may provide an important clue to the answer. We think that at least one Amazonian population of this species of lower termites engages in some form of fungus cultivation. If our hypothesis is correct, the insects would constitute, in some real sense, a "missing link" of termite evolution.

Such a possibility might sound—to coin what is perhaps an apt phrase—like wood candy: a delight to specialists like us who can digest the stuff, but hardly of more than passing interest to the rest of science. But because they rely completely on other organisms to process the wood they ingest, lower termites are ideal animals for the study of symbiosis. And symbiotic relations—the coexistence, in physical contact, of two (and often more) different species of organisms during most of their lives—place the generally touted mechanisms of evolution in a revealing light. Classic Darwinian evolution—the process whereby heritable variation gives rise to new species—must occur, but how? Permanent symbiotic relations may well be the most important factor underlying

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rapid evolutionary change, and the study of termite symbioses could offer important insights into the process by which fungal agriculture evolved.

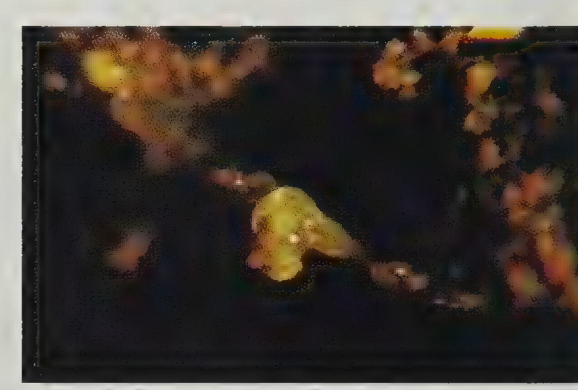
The story of *H. tenuis* began for us in January 1999, when a team of graduate students, including Wier, visited the Tiputini Biodiversity Station in the eastern lowlands of Ecuador. The station, on the Tiputini River deep in the Amazon rainforest, is a biologist's delight. Great buttressed trees tower overhead; epiphytic bromeliads, kin to pineapples, perch on many branches and trunks. By the time sunlight filters through the strangler figs enveloping their host trees, and the few remaining rays meet the diversity of luxuriant palms, there is little light left over for ground cover. The forest floor is almost bare.

Wier had come to study the dangling, clinging vines, the epiphytes, and the colorful fungi of the rainforest. But he also sought to document symbiotic microorganisms: in standing water, in the trees, and associated with termites. He saw termites everywhere in the dead wood surrounding the biodiversity station—even in the hardwood steps built into the muddy trails. Throughout his visit he made photographs of rotting logs covered with cup fungi, and of walking palms, many infested with termites. He didn't know at the time that one colony was *H. tenuis* (that identification was made later by Rudolph H. Scheffrahn of the University of Florida in Fort Lauderdale); but once back in the laboratory, he easily determined that all the insects that looked like white ants in one rotting log carried protist symbionts.

Termites, a group of some 6,000 species, have lived in wood and digested it for at least the past 100 million years. The group's ancestry can be traced to a lineage of wood-ingesting cockroaches.

Presumably, the first termite family to evolve was the cockroach-like Mastotermitidae, the members of which once ranged across the globe. Today only one species remains, and its range is limited to the area around the port city of Darwin, Australia. Other families of lower termites, which rely on both protists and bacterial symbionts to digest their woody food, include the Rhinotermitidae, the familiar subterranean termites that love wooden houses; Hodotermitidae, foraging harvester damp-wood termites, many native to Africa; and Kalotermitidae, which eat and nest in dry wood.

The remaining termites are considered "higher," because of their apparently more complex social organization. They no longer rely on hindgut protists to digest their food. Instead, these animals—by far the majority of termite taxa—have evolved various other food-gathering strategies: some higher termites even enjoy a diet of leaves, fruits, nuts, decaying plant matter, and soil bacteria. Other higher termites, however—though lacking the complex wood-digesting, swimming gut protists of their lower termite relatives—still rely on woody fiber made of cellulose and lignin. To extract the nutrients from the cellulose, they cultivate fungi, which they fertilize with wood chips, then harvest and devour.



This milky white dot, a growth of the fungus Delortia palmicola, *might hold the key to the origins of termite agriculture.*

Whatever the skills of a professional human mushroom grower, they pale next to the virtuosity of the termite farmers. The termites prepare and fertilize the soil; prune the unruly growth of filamentous hyphae, or threads of tissue that make up the

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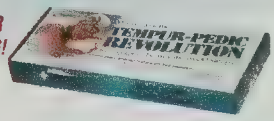

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body of the fungi; incessantly weed out a multitude of extraneous fungi, bacteria, and debris in order to grow pure cultures of *Termitomyces* ("termite fungus"); and finally reap their tasty harvest—all with a social dexterity that even the most gifted laboratory team of microbiologists cannot imitate.

In the course of millions of years of practice and extraordinary evolutionary success, fungal agriculture has led to the development of termitaria, mounds that can house as many as several million individual termites and their crops. J. Scott Turner, an animal physiologist at the State University of New York in Syracuse, has studied, at length, the atmospherically regulated mounds of *Macrotermes natalensis,* a southern African mound-building species [*see "A Superorganism's Fuzzy Boundaries," by J. Scott Turner, July/August 2002*]. These termitaria are spectacular structures, rising as high as nine feet in the air, and Turner has documented the many complex ways the termites can regulate the internal environment of the termitaria. For example, such a termitarium maintains levels of carbon dioxide and humidity far above those of the outside air, and it can harness the wind for gas exchange, acting like a lung. The system relies on hundreds of thousands of worker animals, constantly communicating via pheromones, both to build and to maintain the mounds.

The key asset of the entire termite city is its fungus farm. Workers scour the hinterland for wood and other vegetation, then carry it back to the termite city in their guts. Upon returning to the mound's fungal gardens, they excrete their forage: a mash made up of wood, all kinds of fungi (both *Termitomyces* and others that the workers inadvertently swallow as they labor outside), and microorganisms. The mycologist Elio Schaechter, in his charming book *In the Company of Mushrooms,* has closely observed what happens next:

> Once excreted, the fungal mycelium [the mass of hyphae emanating from the fungus] grows into tiny spheres, about the size of a small pinhead. These spheres, packed with fungal spores, are the most prominent feature of the fungus gardens. To the termites, the scene must appear as a field of tightly packed giant puffballs would to us.

Thus the termites do not feed directly on the wood-fungal mash; the wood is fodder for the *Termitomyces.* The termites themselves eat the pinhead-size bits of mycelium for breakfast, lunch, and dinner.

The insects control and restrict the growth of their fungi much the same way a gardener might force the flowering of a bulb indoors, manage fertilization, or train the shape of a shrub. That active care prevents the formation of mushrooms—the sexually mature stage of the fungal group known as Basidiomycota; the presence of mushrooms in a termitarium is a sure sign that the termites have died.

H. tenuis *workers and soldiers on a log*

Although naturalists first observed the fungus-termite relation as long ago as the late eighteenth century, investigators do not know when, where, or in which species or set of species fungal farming developed. Students of nature know that any termite (whether higher or lower) that swallows wood inevitably swallows fungal spores. But the question of how and when that inadvertent feeding on the part of ancestral lower termites developed into *Macrotermes* farming culture has remained unanswered.

The Ecuadorean *H. tenuis* may hold part of the answer. As we tried to keep the termites alive in our laboratory, a crisis tipped us off to something special. We had been pleased at how well our damp termites were thriving. Then an enthusiastic student inadvertently overwatered the colony just before a weekend, leaving a flood inside the termites' box. Such errors usually kill laboratory colonies of termites of any species. The problem is not so much that the termites drown, but that overwatering encourages fungi to grow so copiously that they overwhelm the boxed-in insects. A pool of water in an incubator can kill a colony of wood-eating termites in a weekend.

The following Monday morning should have been grim. But surprisingly, the flooded *H. tenuis* colonies thrived. To our untrained eyes, their response seemed comparable to the pheromone-driven repair work that *Macrotermes* undertake after an abundant rainfall. Flooding, it seems clear in retrospect, must be commonplace in the termites' Ecuadorean habitat. The colonies that actively respond to their ravages are the ones that survive to leave offspring.

And there was more. Less than a week after the flood, minuscule, translucent dots, the color of skim milk, began covering the rotten wood of the log. Within two weeks the dots grew to the size of pinheads, and stayed that way for months. Under the microscope we could see that the pinheads were almost pure cultures of a single distinctive type of fungal spore—much purer than the mixture of species that one would usually expect to find growing in a natural sample. The spores themselves were made up of three cells clumped close together [*see photograph on page 74*], all turgid and, indeed, nearly bursting

(Continued on page 74)





SCENIC BYWAYS

things to see and do on the road

Charlotte-Genesee Lighthouse

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Photos courtesy of National Scenic Byways Online

Niagara Falls

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NEW YORK STATE

The 454-mile **Seaway Trail**—the state's only National Scenic Byway—parallels the St. Lawrence River, Lake Ontario, the Niagara River, and Lake Erie, carrying visitors through an eclectic array of large towns, quaint villages, picturesque bays, and rolling farmland. Harbors, lighthouses, fishing, wildlife, and history all contribute to the trail. Plan on at least four days to drive along the entire route, and take along bicycles: the Seaway includes many miles of excellent bike trails.

For a one-of-a-kind New York adventure, plan a vacation along the state's Scenic Byways.

Start your exploration at the Seaway Trail Discovery Center in Sackets Harbor. Housed in the Federal-style Union Hotel, dating from 1817, this one-of-a-kind museum offers three floors of interactive exhibits featuring the trail's many attractions. Sackets Harbor itself has many historic homes. As you drive along Lake Ontario's eastern shore, stop to explore protected harbors and historic beaches, where you may sail, fish, or rent a boat. In the Sandy Pond area, you'll enjoy the beauty of fragile barrier beaches, dunes, lagoons, and freshwater marshes. In Henderson Harbor, birdwatchers should seek out the secluded Lake Ontario Islands Wildlife Management Area, which includes Little Galloo Island. Little Galloo is home to a populous shorebird rookery: some 60,000 pairs of birds are found here. It has the largest ring-billed gull colony in North America, New York's only Caspian tern colony, and scores of cormorants, herring gulls, great black-backed gulls, and black-crowned night herons.

The Seaway Trail's most well-known attractions include the phenomenal Niagara Falls, the Thousand Islands, and historic lighthouses. For more information, phone 800-SEAWAY-T, or write to Seaway Trail, Inc., 109 Barracks Drive, Sackets Harbor, New York 13865. History buffs should ask for a copy of the *Seaway Trail Guide to the War of 1812,* which details its 42 historic war sites.

Past Lake Champlain and beneath the Adirondack Mountains, stretching from the Mohawk River to Quebec, visitors will find the **Lakes to Locks Passage**, a designated All-American Road. This byway parallels the lake and its canal, with plenty of history, scenic views, and state parks abundant with hiking trails, lakeside beaches, and wildlife. Bring along bicycles, because the road's bikeways are known as some of the best cycling trails in the country. Lake Champlain is especially delightful for sailing and boating but will also appeal to lovers of history. Long the home of the Huron, Algonquin, and Iroquois, the strategically located lake was the site of many battles throughout the French and Indian War, the War for Independence, and the War of 1812.

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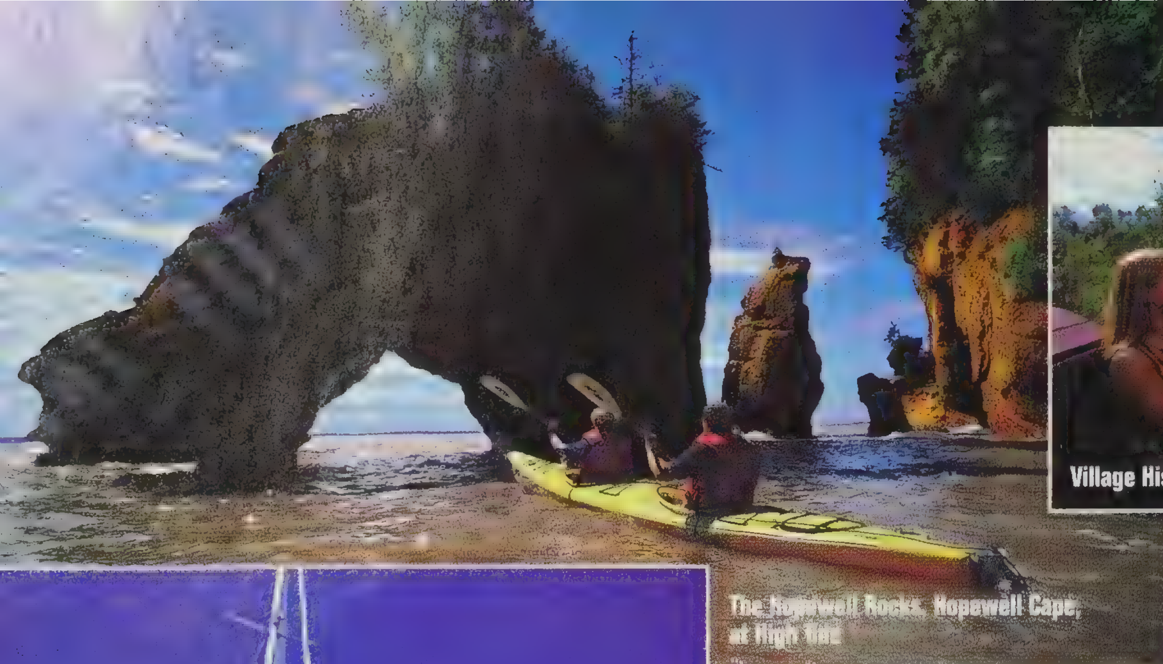
The Hopewell Rocks, Hopewell Cape, at High Tide


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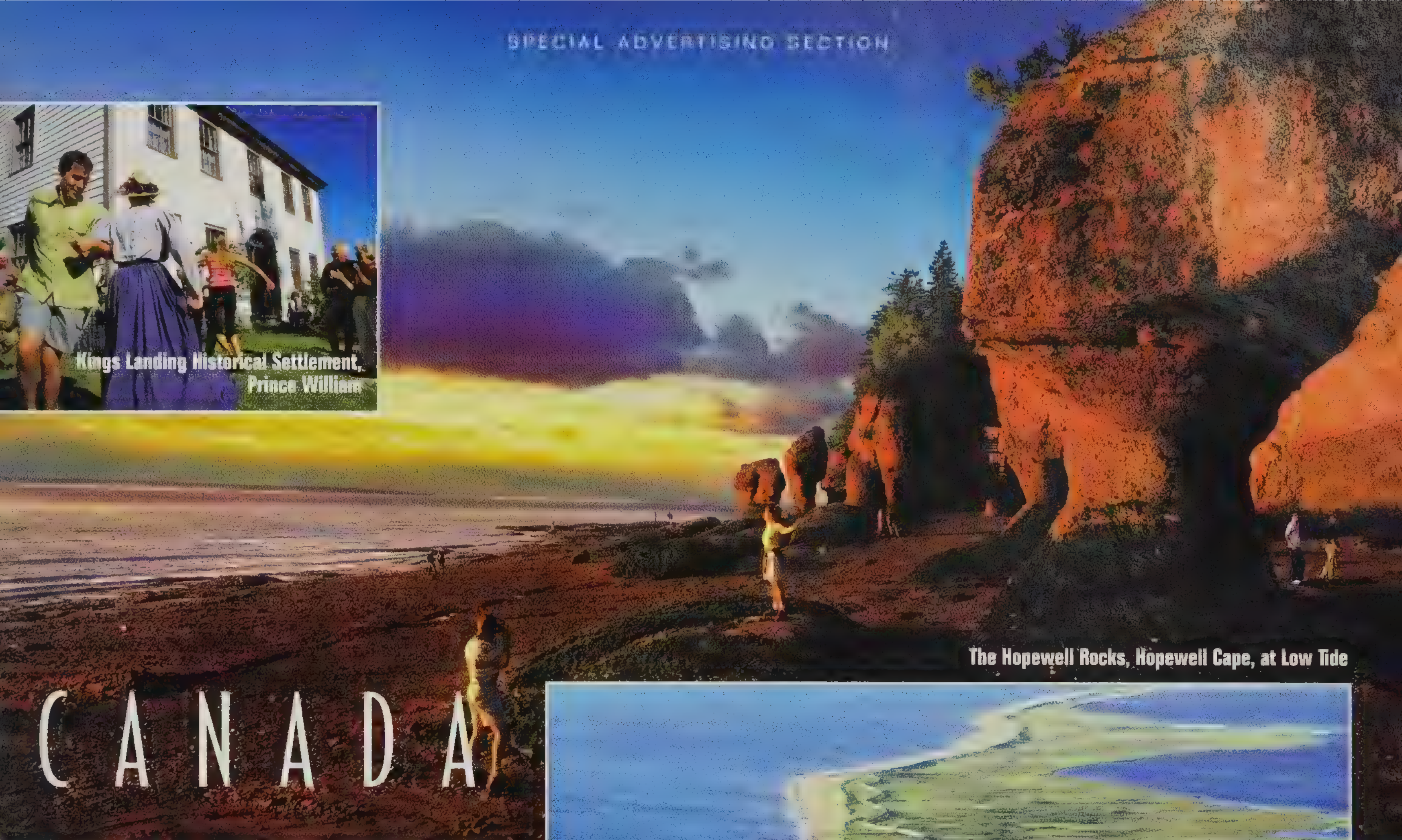

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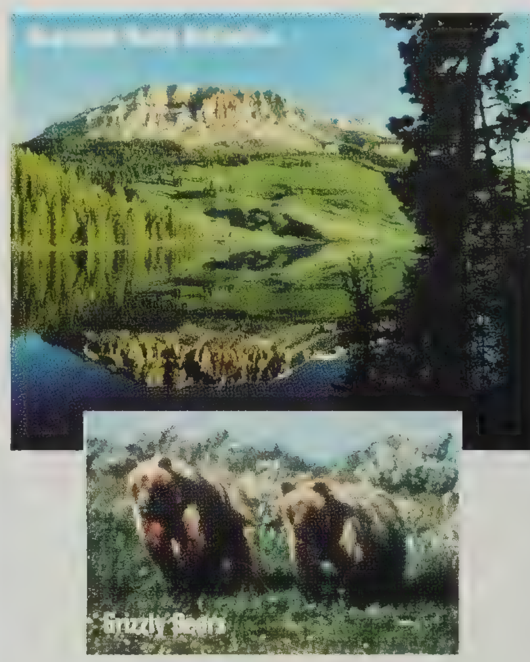
WYOMING

Wyoming has 14 scenic byways or "backways," including what many would call the most beautiful highway in America—the Beartooth Highway (U.S. 212), built in the 1930s. From the Custer National Forest to Yellowstone National Park, the Beartooth Highway is one of the most spectacular



Photos courtesy of USFS and National Scenic Byways Online

National Forest routes on this continent. The Beartooth offers travelers the ultimate high-country experience as it winds through the Custer, Shoshone, and Gallatin National Forests.

The highway's sixty-nine miles cross from lush forests to alpine tundra. The rugged Beartooth area boasts 20 peaks reaching over 12,000 feet in elevation. Glaciers are found on the north flank of nearly every mountain peak that is over 11,500 feet high. Stop along this byway to hike across broad plateaus and to admire Rocky Mountain goats, moose, black bears, grizzly bears, marmots, and mule deer.

Points of interest include the spectacular Yellowstone National Park, the country's first and largest national park, and Shoshone National Forest, which sprawls along Yellowstone's eastern border.

Learn more about the Beartooth at www.byways.org.

A R I

The Grand Canyon State's scenic byways and historic roads transport visitors to all of its natural wonders and many hidden treasures off the beaten path.

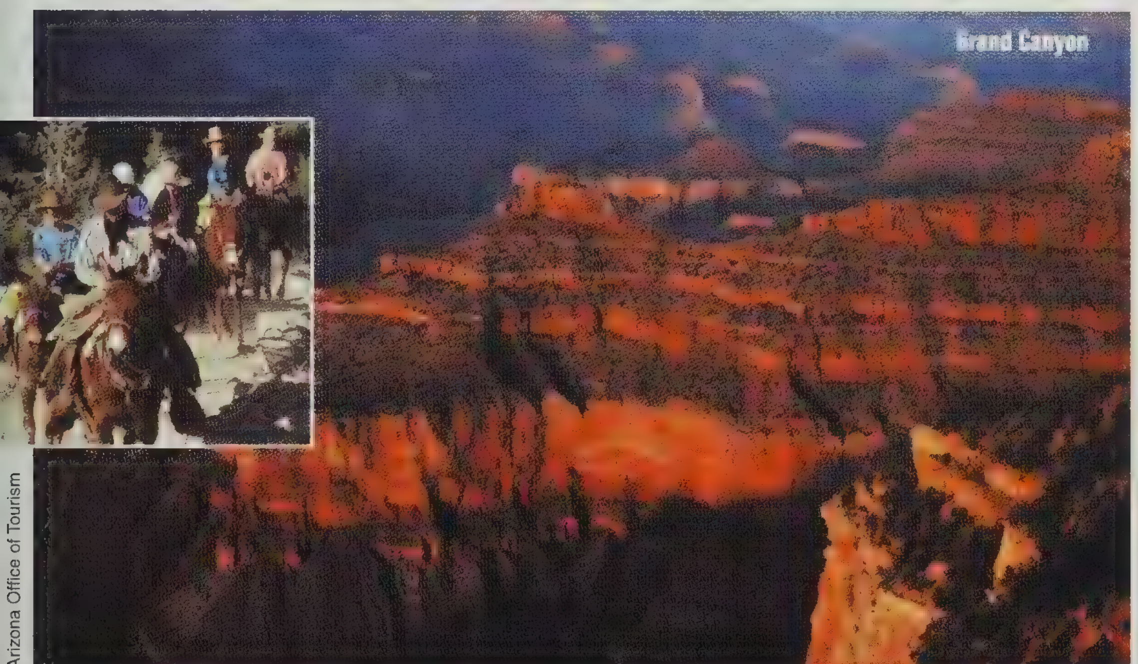
Get your kicks on Route 66, probably Arizona's most famous road, which crisscrosses the state from east to west. Although portions have been replaced by an interstate, this historic route still manages to convey what it was like to travel across the United States in the 1920s. Route 66 crosses the Navajo Indian Reservation and nears the Hopi Indian Reservation, where you might pick up some Native American crafts. The road is also not far from Canyon de Chelly, Walnut Canyon, Meteor Crater, and the Homolovi Ruins.

The Kaibab Plateau–North Rim Parkway, a national Scenic Byway, crosses over the gorgeous Kaibab Plateau and travels through two forests: the Kaibab National Forest and the Grand Canyon National Park. There are plenty of places to hike and camp along the route. Groves of golden aspen, flowery meadows, ponds, and outcrops of limestone break up the dominance of the regal coniferous forest. This byway travels to the brink of the spectacular north rim of the Grand Canyon, which is 1,000

Arizona Office of Tourism

ZONA

feet higher than the south rim. Wildlife is abundant across the Kaibab Plateau, which is over 8,000 feet in elevation. Allow at least an hour to explore this 42-mile-long Scenic Byway. For more information, visit www.ArizonaScenicRoads.com.



Arizona Office of Tourism

Michel Bonato

Bonoit Chalifour

QUEBEC

For a vacation site that's secluded, beautiful, and undiscovered, head to the Îles de la Madeleine Islands. These islands are located in the middle of the Gulf of St. Lawrence, a five-hour ferry ride from Prince Edward Island (Souris). You can also take a ferry cruise directly from Montreal. However you get there, these lovely barrier islands are worth the trip. Part of Maritime Quebec, the Îles de la Madeleine will enchant you with their unspoiled white beaches and fragile dunes, green valleys, and red cliffs. The steel-gray ocean surrounds the islands and is visible from just about every house.

Michel Bonato

The main road, Route 199, connects the six main islands. Most of the road's 65-mile length crosses long stretches of dune landscape, where motorists spy sandpipers, plovers, and seagulls along the beaches, and the red sandstone cliffs that form much of the islands' coastline. Small, wooden houses, often painted in bright colors, dot the landscape. Fishing is a way of life here, as can be seen by the multitude of lobster boats in the harbor at Grande-Entrée, which locals call the "Lobster Capital of Quebec." Try a lobster roll dipped in butter or a fine gourmet meal of snow crabs or scallops at one of the islands' many restaurants.

Harbor and gray seals are fairly common around the Îles de la Madeleine and can be easily spotted in their natural habitat. About 200 species of birds, mostly marine and shorebirds, live or pass through the islands. The best times for birding are in the spring and fall during the nesting and migration seasons. Many of the nesting birds live in colonies: the northern gannet, the blacklegged kittiwake, the heron, the double-crested shag, the thick-billed murre, the Atlantic puffin, and the razorbill. The endangered piping plover, found nowhere else in Quebec, nests on the islands' beaches.

The Îles de la Madeleine have two nature reserves: Île Brion, whose stunted forests are home to over 140 bird species, and Pointe de l'Est in Grosse Île, an essential stopping point for migratory shorebirds and ducks. Rocher aux Oiseaux, an elevated rock northeast of Grosse Île, is difficult to reach (reserve a boat tour), but worth the effort: this refuge for colonies of petrels, northern gannets, razorbills, murres, and gulls is one of the most important bird watching sites in the gulf.

For more information, visit www.tourismeilesdelamadeleine.com or call 1-877-624-4437.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A paradise tree snake flares its ribs and curves itself into an S as it glides through the air.

Serpents in the Air

A little contortionist can go a long way.

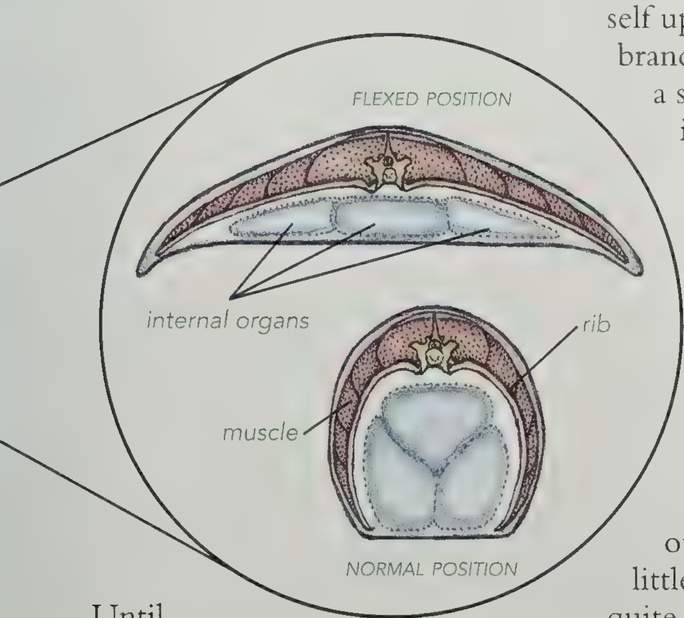
Story by Adam Summers ~ Illustration by Patricia J. Wynne

The ophiophobe worries, somewhat irrationally, about snakes—whether they're slithering across the sidewalk, lurking in laundry hampers, or even appearing on television. If you, too, are burdened by such anxieties, you might just skip this month's "Biomechanics." There's plenty to engage you in the rest of the magazine, and what you'll undoubtedly retain from this column will be just one more item in the list of directions from which snakes can suddenly appear: from above.

Although as a group snakes appear singularly unsuited for aerial exploits, herpetologists (those intrepid biologists who specialize in reptiles and amphibians) have heard credible accounts of "flying" snakes for more than a hundred years. Only lately, however, has one investigator begun to exhaustively document the extent and mechanics of those animals' aeronautical talents.

To most people, any airborne snake is a flying snake—why bother with fine distinctions when the very idea of an airborne snake is probably unnerving enough to contemplate in the first place? But to biologists, an animal is properly called a flier only if it can generate enough force to gain altitude in still air. A critter is a glider (but not a flier) if it can manage at least a foot of horizontal travel for every foot it falls. An animal that moves less in a horizontal

direction than it does in the vertical is said to "parachute" (unless it jumps or falls). A passive aerialist, of course, might catch an updraft and so soar to a higher altitude, but the lack of actively generated upward force still technically disqualifies it as a flier.



Until recently herpetologists thought all flying snakes were parachutists, barely able to slow their descent, let alone to take active control of their own direction and altitude. After all, such control would seem to require a body part in the shape of an airfoil, and tubular snakes apparently lack the broad, thin surfaces that guide the descent of such better-known gliders as flying squirrels, colugos (flying lemurs), frogs, and lizards. But John J. "Jake" Socha, a biomechanist who recently received his doctorate from the University of Chicago, has, by reconstructing the three-dimensional flight path and mechanics of the snakes' glides, discovered that it doesn't necessarily take webbed legs—or limbs at all—for an animal to turn a fall into a long glide.

In fact, explaining what it takes for a snake to glide sounds a bit like an episode of *Sesame Street:* today's program is brought to you by the letters J, S, and C. Socha worked with the paradise tree snake, *Chrysopelea paradisi,* a native of Southeast Asia, on the grounds of the Singapore Zoological Gardens. To get the snakes to jump, he induced them to slither out on a perch more than thirty feet above the ground. When a flying snake prepares to jump, it dangles like the letter J from a branch. It then flings itself upward and away from the branch, only to begin falling at such a steep angle that few would call it anything but a plummet.

Yet after falling less than ten feet, the two-foot-long snake assumes an S shape and begins to undulate, much as if it were crawling across the ground, albeit more slowly and with more lateral movement. At the same time, the angle of its trajectory begins to flatten out, eventually decreasing to as little as 13 degrees. The snake—quite deft at avoiding obstacles—seems to swim through the air; in Socha's tests the snakes landed as far as sixty-nine feet from the thirty-foot-high launch point. In the shallowest moments of their glide (when their fall angle has decreased to its minimum), the snakes can travel nearly four times farther horizontally than they fall vertically, which easily surpasses the one-to-one benchmark of a gliding animal.

One of the most important factors in the snake's midair shift from free fall to glide is a dramatic increase in the width of the animal's body. Like most other snakes, a flying snake is roughly circular in cross section. But while a member of *Chrysopelea* is falling after launch, it flares its ribs so far outward that its belly becomes concave. With its body molded into a highly flattened C, the area of the snake's ventral silhouette—that is, its silhouette when seen from below—nearly doubles. It's as though the hood present on some cobras were extended along the entire length of the paradise tree snake's body.

The flattening of the snake essentially turns the animal into an airfoil: the increase in body width effectively halves the ratio of the snake's body weight to the area of its underside, a measure known as wing loading, and a crucial indicator of aerobatic talent. For example, the wing loading of a highly maneuverable bird such as the chimney swift is ten times smaller than that of the aeronautically challenged common loon. Wing loading in the paradise tree snake falls between those two extremes, but it's closer to that of the swift.

Experts in aerodynamics have also suggested that the snake's tight S-bends make its entire body act like a highly slotted wing. In airplanes, slotted wings have gaps that run along their entire length, from fuselage to wingtip; because of the way air flows through the gaps, such wings develop more lift at low speeds. Flaps along the trailing edge of airplane wings have the same effect. That principle is also at work in the spread between the feathers on the wing tips of the best low-speed gliders, such as vultures and hawks. The gaps between the bends of the S-shaped snake in flight could produce more lift than the snake would have if it shot, arrowlike, through the air. Any extra lift is crucial for maneuvering while gliding.

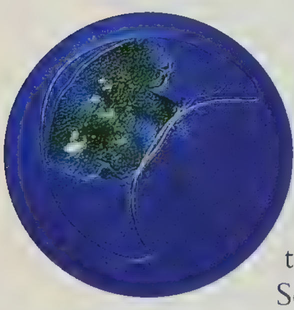
The advantages of gliding for a snake seem obvious: moving through the air from tree to tree bypasses a host of earth-bound predators, and a flying snake threatened by an arboreal animal can just launch itself out of the tree. But the paradise tree snake glides so expertly that it could, in principle, mount an airborne attack, either on a passing bird or on some more pedestrian prey that, like the ophiophobe, is expecting anything but a snake assault from above.

Adam Summers (asummers@uci.edu) is an assistant professor of ecology and evolutionary biology at the University of California, Irvine, and he once caused a snake to appear unexpectedly in a laundry hamper.

A Plenitude of Ocean Life

A new census of the sea is revealing that microbial cells thrive in undreamed-of numbers. They form an essential part of the food web.

By Edward F. DeLong

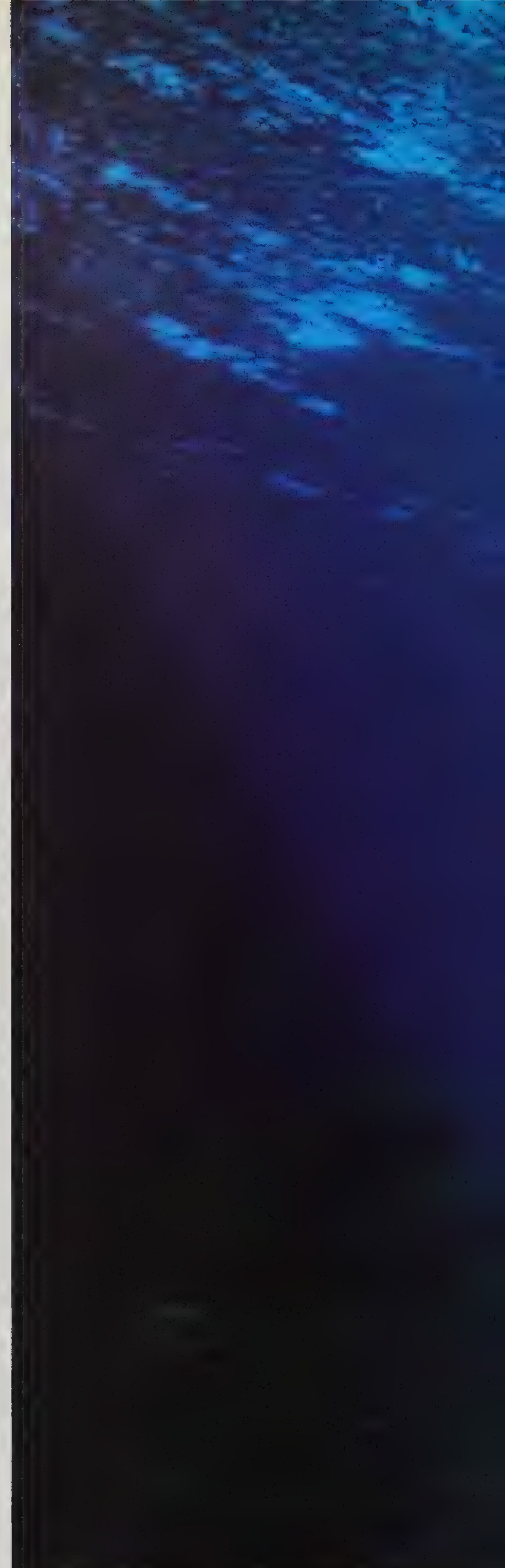


Pyrocystis lunula, a dinoflagellate

The *Polar Duke,* our ice-worthy Norwegian vessel, was immobilized—beset, to use the correct nautical term—by enormous sheets of sea ice. It was early August 1995, late winter in Antarctica, and the two-meter skin of frozen seawater that enveloped us was a seasonal expression of the Southern Ocean. Our destination was Palmer Station, a research station run by the National Science Foundation and situated on Anvers Island, off the Antarctic Peninsula. Evidently, though, our group of American scientists and support staff had set out just a little too soon. It took ten days for a change in wind and the breakup of the ice pack to free the ship, but by then we were low on fuel and forced to return to Chile to be resupplied. When we finally made it to Palmer Station, we were a month behind schedule. Only two months were left of our field season, and that was spent largely on cross-country skis, hauling sleds laden with carboys full of seawater.

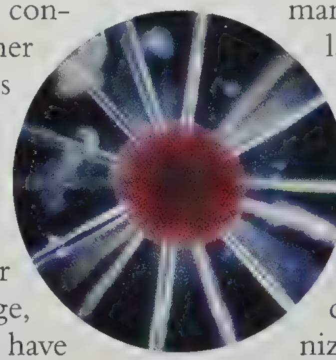
So went the first visit of my research group to Antarctica. Our aim was to search out and quantify the range and biomass of a peculiar group of microorganisms known as archaea. The wisdom of the day was that the critters should not be present at all in the cold, oxygen-rich waters of the Southern Ocean. But a sample of Antarctic seawater collected in early 1990 at Palmer Station, carried to California, and given to us for analysis suggested otherwise. We hoped to show that archaea were major players even below the pack ice.

Archaea (originally dubbed archaebacteria) were not even recognized as a separate branch of life until the 1970s, when the microbiologist Carl R. Woese and his colleagues at the University of Illinois at Urbana-Cham-



A crack in the sea ice in the Antarctic. The frigid waters of the Southern Ocean harbor vastly more microorganisms than was once believed.

paign made a thorough analysis of their ribosomal RNA. This kind of RNA, which plays a role in protein synthesis, occurs in the small structures called ribosomes that exist in every known kind of cell. Because of its ubiquity, ribosomal RNA can serve as a kind of universal bar code for all organisms, placing them in proper historical relation to one another on a single evolutionary tree. Woese concluded that Archaea is one of three major evolutionary branches of life, as deeply rooted as Bacteria and Eukarya. (Eukarya, whose cells contain a nucleus and other structures, encompass plants, animals, fungi, and protists—protozoa, algae, and lower fungi.)


Radiolarian

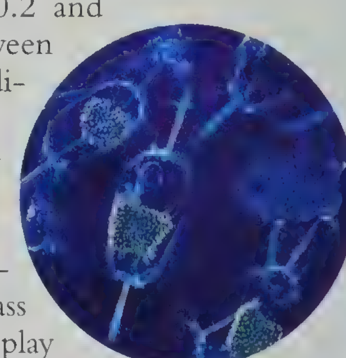
Apart from their evolutionary heritage, archaea appeared to have one thing in common: they thrived in extreme environments. At the time of our expedition, we knew some lived in saline lakes five times saltier than the ocean; some lived in anaerobic (oxygen-free) habitats, where even trace amounts of oxygen would prove lethal; and some lived in hot geothermal environments that would cook most organisms to a crisp. Among them was *Pyrolobus fumarii,* which could grow in anaerobic deep-sea hydrothermal vents at temperatures as high as 235 degrees Fahrenheit.

Our surveys of the frigid, aerobic Antarctic waters turned up archaea in great and unexpected numbers. Indeed, we have learned that cold-adapted cousins of heat-loving archaea appear to be flourishing in marine waters both shallow and deep and at all latitudes—polar, temperate, and tropical. They turn up in the guts of abyssal sea cucumbers and in sediments at the bottom of the sea. Quantitative surveys now show that archaea comprise between 20 and 30 percent of all the microbial cells in the ocean.

Plankton, sea life that drifts with the currents, ranges from the macroscopic to the microscopic. The so-called picoplankton comprises cells between 0.2 and 2.0 microns across. Anything smaller (such as a virus) is part of the so-called femtoplankton.

The discovery and enhanced understanding of so many new microbial groups stems not only from the quest to look in new places. Modern-day microbe hunters also have new, high-tech tools for identifying and counting microbial life. In the past the method of choice had simply been to culture a sample of, say, seawater and then see what grew. Although that approach is still being perfected, many cells stubbornly refuse to grow under laboratory conditions. The new techniques, some based on the tricks of molecular biology, enable biologists to find out what is in the samples by direct observation.

Microbial life is proving to be far more diverse than cultured samples could suggest. A lot of the newly recognized life in the oceans is so small that its size is reflected in its name: picoplankton. The plankton comprises the floating "wanderers" of the sea, single-celled and multicelled plants and animals (including many immature larval forms) that move primarily by drifting with the currents [*see illustration at left*]. Anything smaller than 0.05 millimeter but larger than 2.0 microns, capable of passing through fine-mesh nets, is considered nanoplankton (the prefixes "nano-" and "pico-" do not literally correspond to such measurement units as the nanometer or the picometer; they arise instead from naming traditions in marine biology). The picoplankton comprises the smallest cells, ranging between 0.2 and 2.0 microns across (between 1/500th and 1/50th the diameter of a human hair).


Ditylum brightwellii diatoms

Until the 1970s, picoplankton was thought to be an insignificant element of the marine microbial food web; its biomass seemed much too low to play a primary role. But estimates of the numbers of microscopic planktonic organisms climbed dramatically in the late 1970s, when the so-called epifluorescence microscope was developed. This instrument, coupled with the use of flu-

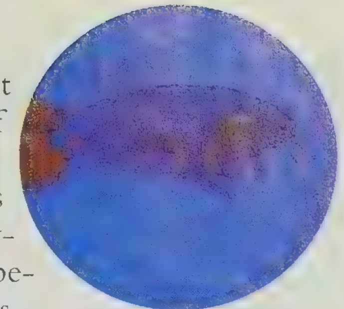
orescent dyes that cause individual microbial cells to glow under ultraviolet light, enables the cells to be easily seen and counted. Technically, the process is an easy one. You simply add the dye, which binds to DNA in a sample of seawater, wait five minutes, collect the seagoing microorganisms on a filter, and observe them under the microscope. It is now known that the density of microorganisms ranges from tens of thousands per milliliter in the deep ocean to millions per milliliter in the energy-rich waters near the surface.

Corethron, a genus of phytoplankton

One might object that such a technique could not distinguish live cells from a lot of dead detritus floating around in the water. Studies in the early 1980s, however, which drew on biomedical techniques to measure the synthesis of DNA and protein, showed that marine picoplankton can double in biomass every day or so. So the cells observed with fluorescent dyes are very much alive and metabolically active. (In fact, the only reason the seagoing populations of picoplankton stay roughly constant is that protist predators are busily grazing on them at about the same rate as the picoplankton reproduces.)

The metabolic activity within the huge biomass of picoplankton represents a massive flow of carbon and energy. Some of the carbon is given off as carbon dioxide gas, but much of it remains locked up in organic molecules that help sustain the rest of the food web. Particularly important to the carbon cycle as well as to the entire oceanic food web are the microorganisms that live at or near the ocean's surface: the forests of the sea are microscopic.

It has been known for some time that the top 600 feet of the water column in the oceans is a region of intense photosynthetic activity. Carbon dioxide is combined with the energy of sunlight to produce a rich food harvest that supports all the other inhabitants of the ocean's surface, and most denizens of the deep as well. As recently as twenty-five years ago, all that productivity was credited to eukaryotic algal species, including diatoms, dinoflagellates, and their relatives. That now turns out to have been a faulty conclusion that arose from a major oversight.



Copepod with two egg sacs in tow

Shortly after epifluorescence microscopy was developed, the first of a new kind of photosynthetic microorganism was discovered: marine picoplanktonic cyanobacteria of the genus *Synechococcus.* Biologists were already familiar with cyanobacteria—they used to be called blue-green algae—because some kinds collect into so many individuals that they are visible in the aggregate. But the new cyanobacteria were much smaller,

Alexis Rockman, *Ice Shelf,* 2003

A "black smoker," or hydrothermal vent. Heat-tolerant microorganisms survive here, providing nutrition for other forms of life.

more abundant, and far more widely distributed than any previously known kind of "algae."

Like plants and genuine algae, cyanobacteria possess a kind of chlorophyll—so-called chlorophyll *a*—that enables them to "fix" carbon in the presence of sunlight, that is, to remove the carbon atoms from carbon dioxide gas and incorporate them into organic molecules. In the process the cyanobacteria give off oxygen, as do all plants that contain chlorophyll. Unlike plants, though, cyanobacteria lack a second kind of chlorophyll, known as chlorophyll *b*, which in concert with chlorophyll *a* helps plants capture light.

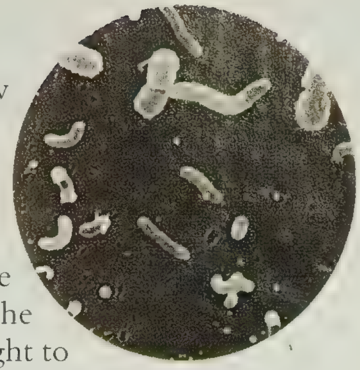
Mantis shrimp larva

But cyanobacteria do harbor certain other pigmented proteins that help them harvest light energy. The proteins, known as phycobiliproteins, fluoresce red under the epifluorescence microscope, and that is how the new, tiny cyanobacteria were so easily detected and enumerated. By 1979, John B. Waterbury of the Woods Hole Oceanographic Institution in Massachusetts and John McNeil Sieburth of the University of Rhode Island on Narragansett Bay had shown that *Synechococcus* was extremely abundant in coastal and open-ocean environments, reaching densities greater than 100,000 cells per milliliter. Later experiments showed that at certain times and places these cells can be responsible for as much as half of the primary production of food in the ocean.

Ceratium longipes, a dinoflagellate

Then, in the late 1980s, the oceanographers Sallie W. Chisholm of the Massachusetts Institute of Technology and Robert Olson of Woods Hole discovered another small (less than a micron in diameter), red-fluorescing kind of cell that was even more abundant than *Synechococcus.*

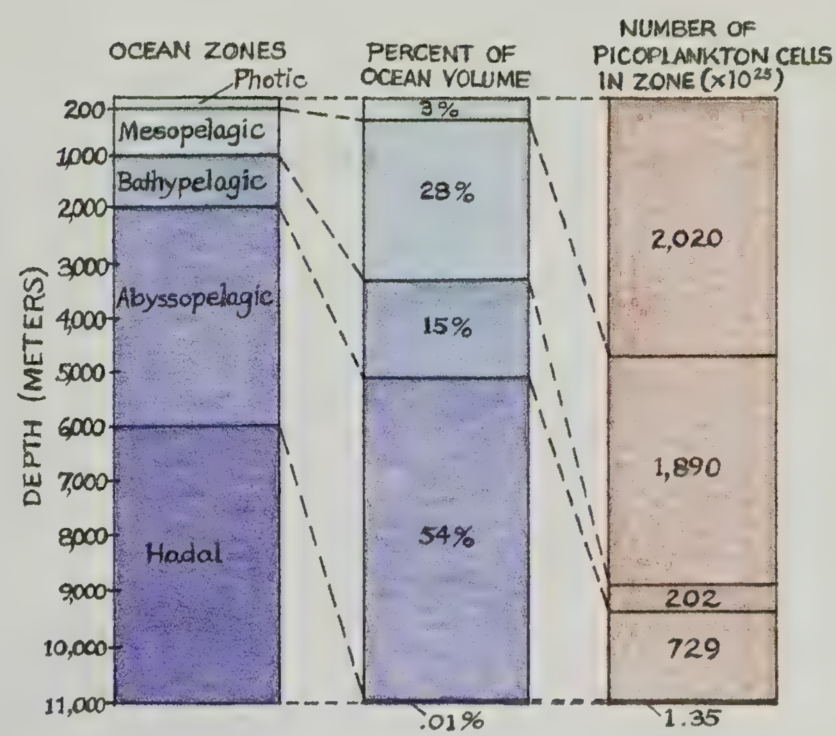
The new cells—in size, also a kind of picoplankton—were eventually cultured and isolated in the laboratory and given the genus name *Prochlorococcus.* They turn out to be closely related to *Synechococcus,* but the two genera differ in their pigment composition. Chisholm and her coworkers at MIT have now also determined the entire genome sequences of two *Prochlorococcus* strains, which represent high- and low-light-adapted "ecotypes." The low-light-adapted strain has significantly more genes than the high-light strain, perhaps because it needs more accessory proteins to efficiently gather light that is in short supply.



Picoplankton

Field experiments have now shown that in the open ocean *Prochlorococcus* cells reach concentrations of hundreds of thousands per milliliter of seawater. In fact, *Prochlorococcus* constitutes half of the total chlorophyll-based biomass in the ocean. So picoplankton, once thought to be sparse and functioning mainly to recycle organic matter back into plant nutrients, proves to be much more central to the carbon cycle. The fact that picoplanktonic cells circulate in such vast numbers and are grazed upon by protists means that they supply nutrients directly to larger organisms. This microscopic portion of the food web has been dubbed the "microbial loop."

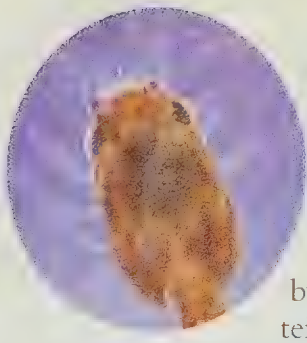
In our laboratory at the Monterey Bay Aquarium Research Institute, my colleagues and I are exploring a new technique of archiving the



Although the photic zone represents a small percentage of the ocean's volume, it contains the highest concentration of picoplankton cells. The smallest ocean zone by volume is the Hadal, named after Hades for its great depth.

genomes of microorganisms en masse. The idea is to get a better understanding of the genetic, biochemical, and physiological properties of the organisms, as well as of their natural history.

Large DNA fragments, as long as 200,000 base pairs, are gathered higgledy-piggledy from mixed microbial populations and then cloned to create, in effect, an archive of microbial genetic diversity. Such

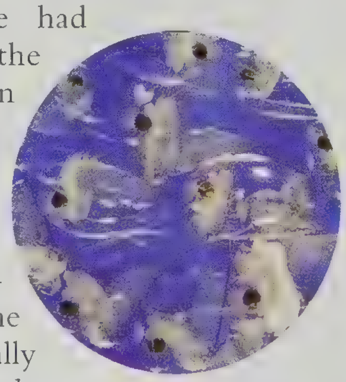


Mysis shrimp larva

a "library" serves as a repository of all the genes and genomes present in the original microbial population that was sampled. We can quickly search such libraries for the presence of particular genes—and by extension, the presence of the proteins and metabolic functions that the genes encode. We can also screen our libraries for markers that identify just which species of microorganism the genes belong to. In addition, proteins encoded by individual genes can be readily produced, making it possible to study their structure, function, and role in the natural world.

Unexpectedly, when we created one of our libraries, we discovered a previously unknown kind of photoprotein. The protein molecule, which came from the genome of a widespread planktonic bacterium, absorbs light of a characteristic wavelength—much as does rhodopsin, the light-sensitive pigment in the human eye. Indeed, the new photoprotein is chemically related to the rhodopsin family. And we have shown that, like rhodopsin, it can convert light into energy usable by the microbial cell. The function it serves for the bacteria—whether, for example, it enables them to fix carbon dioxide the way plants do, or is used to garner more energy for other cellular purposes—remains an open question.

Searching in Monterey Bay, from which the original genetic sample had come, we found that the novel form of rhodopsin occurs in natural communities of marine picoplankton. Further surveys in the oceans from Antarctica to Hawaii revealed that variants of the photoprotein exist virtually everywhere, in varying colors. In deep waters the photoprotein is "tuned" to absorb the blue wavelengths of light most abundant there. In shallower waters, it absorbs the more energetic green light available at the surface. It never fails: every time we dip into the living ocean, we find something new.



Shrimp-like species, order Cladocera

Carbon, nitrogen, and other elements get cycled through the biosphere thanks to a host of microorganisms, but we hardly notice the job they do.

From the study of fossils known as stromatolites, a residue of the larger forms of cyanobacteria, biologists have long known that microorganisms have played key roles in the natural history of the Earth. Cyanobacteria were among the early actors on the stage of life; their capacity for photosynthesis and the oxygen they generated forever altered the global environment. They essentially paved the way for the evolution of other forms of life. Given the abundance of newly discovered cyanobacteria, one can only begin to appreciate what an important role they continue to play in the carbon cycle.

And the cyanobacteria exemplify just one way that marine microorganisms support the biosphere. Bacteria, archaea, and other microorganisms are also vital to the nitrogen cycle: they break down organic nitrogen to produce ammonia; they convert ammonia to nitrate, an essential plant nutrient; and they recycle nitrate into other nitrogen-containing compounds in oxygen-poor zones such as marine sediments. Some cyanobacteria can even synthesize organic nitrogen compounds used to build new cells from simple nitrogen gas. In short, without microorganisms, nitrogen wouldn't cycle at all, and neither would most other elements.

Euglenozoan covered with symbiotic bacteria

It is important to recognize that such transformations depend on an entire community of microorganisms; no single species can carry out all of them on its own. Their interrelations are fantastically complex, forming systems that have been tuned by evolution in ways that work together. Therein lie the reasons for much of our ignorance about them. When they are going about their jobs, when everything is in balance and seemingly normal, we are least likely to notice them. It's only when something breaks down—when, say, excess nitrate in runoff waters creates a noxious algal bloom—that we begin to pay attention.

Microorganisms have been our planetary engineers, the biological stewards of the Earth, for as long as the world has had oceans, at least 3.5 billion years. They still have a lot to teach us. □

A Yen for the Traditional

In modern Japan, street performers sell ritual and nostalgia to compete with high-tech advertising.

By Ingrid Fritsch

Two chindonya performers, hired from Osaka, drum up business for a local shop in Tokyo.

The good old *chindonya,* changing the world from dark to light, people both young and old clap their hands, *chinchira dondon chin dondon. . . .*

—Lyrics from a chindonya troupe in Kumayama, Japan

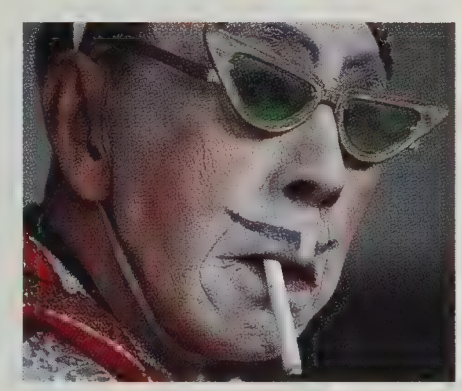
When I tell Japanese people of a certain age that I am an anthropologist interested in *chindonya,* my questions invariably prompt a smile accompanied by a slightly embarrassed giggle. After my informants have reassured themselves that I really mean chindonya, they often ask, "Are they still around? I remember them from my youth."

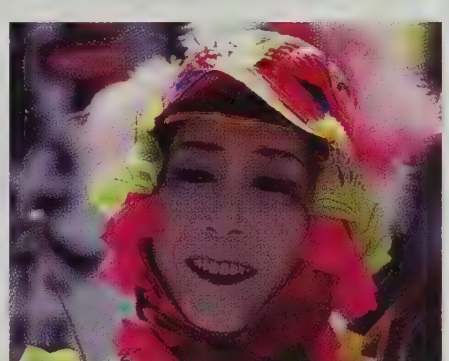
The characters of my curiosity—the chindonya—are troupes of elaborately costumed street musicians hired to draw customers to shops, stores, cabarets, and *pachinko* (pinball game) parlors. Members of these troupes, made up of at least three

people, parade through the streets playing an assortment of Japanese and Western musical instruments. Once their music has attracted a crowd, the chindonya—who also sport sandwich boards or carry banners displaying their employers' advertisements—deliver sales messages, distribute flyers, or perform short dramatic routines such as sword dances.

Their main instrument, the *chindon,* is made up of a small metal gong (the "chin" sound) and two traditional Japanese drums (the "don" sound), mounted together on a wooden frame [*see photograph on opposite page*]. The instrument, developed at the beginning of the twentieth century, is usually played by a man. Accompanying it is a large cylindrical drum, the *gorosu,* generally played by a woman. A clarinet, trumpet, saxophone, or accordion carries the melody. The repertoire includes military marches, old Japanese ditties, songs from kabuki theaters or *yose* variety theaters, and sometimes jazz.

Chindonya still work the streets for advertisers, though their live promotional performances may seem old-fashioned and out of place in Japan's highly industrialized mass-media society. But throughout their history the performers have struggled against obsolescence in the face of social trends, discrimination, world events, and new technological developments. The current resurgence of interest in chindonya has benefited from the cultural need for ritual—and from favorable media attention linking chindonya to "the good old days." Yet even the waves of nostalgia have failed to create any real increase in the demand for their services. Unless the chindonya figure out how to evolve or change with the times, it seems unlikely they will be able to preserve the traditions of their profession in Japanese society.





I first encountered chindonya during a stay in Japan some years ago. On a pleasant day in April, while strolling around the city of Toyama looking for cherry blossoms, I approached the city hall, where a crowd had gathered for the annual national chindonya competition. Suddenly, about twenty-five groups of performers appeared, wearing gaudy makeup and wigs, and costumed as old-fashioned samurai, geisha, and clowns. Before parading, the groups jointly played "Take ni suzume" (Sparrow on the bamboo), an old variety-hall tune now thought of as a kind of theme song of the chindonya. It is one of the few musical pieces common to troupes all over the country.

In the past, becoming a member of a chindonya troupe was a last resort for people who had no prospects in the regular job market. Chindonya were tolerated, but looked upon with disdain. These days the social standing of the performers has improved, partly because of the sentimentalizing of the Japanese folk arts, but also because the chindonya themselves view their occupation in a more favorable light.

Chindonya troupes date back to the end of the nineteenth century, when the Japanese way of life was rapidly becoming industrialized and westernized, and manufacturers decided it was essential to advertise new products. In 1845 in Osaka, a candy salesman named Amekatsu offered his special oratorical and theatrical talents to advertise for a local variety theater. That episode is accepted as the birth of chindonya (though the term does not appear until the early twentieth century), because it is the first documented case of advertising for someone else's products in Japan. Later, under Amekatsu's followers, the activity became known as *tōzaiya,* for the

Troupe members of the Chindon Tsûshinsha agency in Toyama, Japan, display their traditional costumes.

street vendors' attention-getting cries of *"tōzai, tōzai"* (literally "east-west," the Japanese equivalent of "Hear ye, hear ye!"). In 1885 in Tokyo, a similar advertising business known as *hiromeya* (wide eyes) recruited brass bands to march through the streets, sometimes for weeklong parades, to advertise new consumer products such as beer, cigarettes, and toothpaste.

For the past century chindonya troupes have undergone many cycles of waxing and waning. By 1910, when newspapers and other means of advertising had become widespread, many of the performers left their troupes to work as "commentators" *(benshi)* or musicians in silent-movie theaters. When talkies were introduced less than two decades later, many turned back to street performance, joined by touring actors and variety-hall artists put out of work by the popularity of the movies. During the Second World War street performances were prohibited altogether; afterwards, when the economy had recovered somewhat but advertising media lagged, street advertising blossomed again. In those days many circus artists also joined up, and it is estimated there were as many as 2,500 chindonya in Japan in the 1950s and 1960s.

The traditional chindon drum pictured above is named for the sound of the instrument's gong (chin) and of its drums (don).

As television commercials became more widely used, the popularity of street-advertising troupes once again subsided. The oil crisis of 1973 and the ensuing recession reduced the number of chindonya even more drastically. In 1989, when the emperor Shōwa lay dying, all outdoor public performances were prohibited for several months, and the younger chindonya who were able to find other jobs changed their professions.

Today, only thirty to thirty-five chindonya troupes still exist in Japan, and most of their members are more than sixty years old. The majority of the troupes are based in and around Tokyo, where fifteen specialized talent agencies operate. Almost all are family businesses run by chindonya. A few businesses have taken on young apprentices, but most cannot afford to hire outsiders as permanent employees. A number of young performers who have studied with the masters dream of starting advertising agencies themselves, but jobs nowadays are scarce.

Whereas traditional chindonya troupes are still declining, a new

The oyakata (leader and owner) of a chindonya agency in Osaka dips gracefully on the streets of Kyoto.

trend has been successfully promoted by one Osaka-based agency, Chindon Tsōshinsha. Besides doing advertising for small clothing boutiques, restaurants, video shops, or beauty parlors, the firm, which procures about 700 job engagements per year, also carries out campaigns for politicians, city officials, and large companies. In addition, there is a great demand for chindonya to perform onstage at company celebrations, wedding parties, and summer festivals in communities in and around Osaka. By taking on engagements from Japanese businesses with foreign offices, as well as from festivals based abroad, the performers in the agency have also made appearances in Europe, New Zealand, the United States, and in Asian countries outside Japan. Since 1997 the firm has released two CDs and two videotapes.

According to Hayashi Kōjirō, founder of Chindon Tsōshinsha, the role of the chindonya at some events goes beyond mere entertainment and approaches the religious function formerly filled by practitioners of ancient folk rituals. Virtually no practitioners of those old art forms are left today, and so the chindonya are called on to administer cleansing rites for new homes and to perform songs and dances of benediction. Wearing fairly traditional costumes, chindonya can create an auspicious atmosphere, though in fact they are closer in character to cabaret artists than to folk artists.

Whether or not such initiatives can give the chindonya another chance for survival remains to be seen. Veterans and young members alike complain about the emphasis on formal social events and folkloric performances. Such practices, they say, will bring about the downfall of the traditional role of the chindonya: street advertising. That may happen anyway; it would be rash to predict otherwise, given the economic realities of marketing in modern Japan. But it would be just as unwise to predict that the waves of nostalgia and continued antiquarian interest in chindonya will come to an end anytime soon. □

A handbill from 1900 shows a musical band advertising a local miso soup shop.

Temples for Water

The stepwells of western India were a magnificent architectural solution to the seasonality of the water supply.

Text and photographs by Morna Livingston

Interior of the Ambapur Stepwell at Budthal, in the state of Gujarat, India, built in approximately A.D. 1500. When the water table is high, the well's bottom story is underwater.

For all of recorded history the land that is now western India has been seasonally arid. The western monsoon sharply divides the annual cycle into wet and dry, making the earth glisten with rain for three months, then leaving the surface parched for the remaining nine. In the dry months the rivers shrink to a trickle or even disappear.

Small relief sculpture of a swirling shrub, Vadthal Stepwell, 16th century

Millennia ago, to make it possible to survive with such a drastically variable water supply, the region's inhabitants began to devise ways of managing and mediating the resource. In southwestern Gujarat, in the late sixth and early seventh centuries A.D., anonymous masons dug deep trenches into the earth to reach dependable, year-round groundwater. Building upward, they lined the walls of the trenches with huge stone blocks, laid without mortar, and paved the slope of each trench with stone stairs leading up from the water. Thus were built the first stepwells—visible architecture that gave access to an invisible landscape of underground aquifers.

The idea proved immensely practical, and so it soon spread northward to what is now the state of Rajasthan, to areas barely moist enough to farm. Ultimately, several thousand stepwells were built in the towns and villages of western India. The grandest period of stepwell construction spanned half a millennium—from the late eleventh through the sixteenth century—dotting the countryside with exquisitely embellished public monuments, the most extravagant of which is the Rani ki Vav, or Queen's Stepwell, at Patan, Gujarat.

Owing to its delightful qualities and lucid design, the stone stepwell remained the state of the art in Indian water management for more than a thousand years. Yet with the onset of the British Raj in India in the nineteenth century—and with it, the installation of pipes and taps for drawing and distributing water—stepwells fell on hard times. The demise of the stepwell as a source of water, as a gathering place, and as a focal point for many of the deepest feelings of the local people has brought about a tangled mix of environmental, social, and even religious consequences that continue to unfold to this day.

In concept, the Indian stepwell is cunningly simple. Monsoon rain is caught in a depression or behind a handbuilt earthen dam. The rainwater percolates down through fine silt, which screens out particulates, until the water reaches an impermeable layer of compact clay that keeps it from sinking deeper into the ground. In that way the muddy runoff of the monsoon is stored near the surface as a giant sheet of clear water: an underground aquifer.

A Gujarati stepwell simply penetrates the aquifer. It is filled by seepage; there is no obvious water current. The fall and rise of the water level at the bottom of the well reflects the droughts and deluges at the surface. A long staircase, punctuated with landings, leads down to the well at the bottom. When the water table is high, during and shortly after the monsoon, the visitor descends only a few steps to drink or bathe or fill the household vessel; when the water is low, she must descend farther, as deep as nine stories down, to where the final flight disappears into clear, dark water. At each landing is an open porch, supported by columns and protected from exposure to the broiling sun, where the visitor can pause to enjoy a quiet moment in the cool shade.

Much of the soil in the stepwell region is a fine alluvium (which is what makes it such an effective water filter), eroded from the western Himalaya, far to the north. Broken down as it travels, and broken down further by 5,000 years of farming, the soil holds few rocks. Hence the stone for constructing the stepwells had to be brought on wooden-wheeled oxcarts from distant quarries to the chosen sites. Brahmin theologians planned the monuments; low-caste artisans called *somparas* did the engineering and hard labor. Diggers moved the dirt with hoes and lifted it in baskets; masons plied their trade with poles and ropes, hammers and chisels. Some of the workers were women—a practice still evident in the region today.

The heavy blocks of stone were marked with hand-size, deeply carved numbers and letters to indicate their intended placement; the *somparas*, though illiterate, were nonetheless highly skilled at interpreting the marks and then fitting the muddy

blocks together by touch, in accordance with the building plan. All the effort and expense were supported by a flourishing trade in such items as indigo dye, perfume ingredients, and locally printed fine cotton cloth. Stepwells were prestigious public gifts, and the financing of them was worthy of great and wealthy patrons: queens, wives of prominent traders, even successful prostitutes.

A stepwell was host not only to people but also to entire communities of bees, fish, lizards, palm squirrels, parrots, pigeons, and turtles. Images of fish, shrimp, and snakes were carved into half-hidden walls and obscure nooks, delighting anyone who encountered them. With the arrival of every monsoon, the whole world joined the stepwell in hatching, sprouting, recharging, and refreshing. But even the pleasures of water cannot explain the staying power of the stepwell as an institution: its almost unvarying form, its appeal to donors, its astounding beauty. Those persistent qualities derived from its role as a dramatic and imaginative metaphor for the Ganges, the greatest of India's rivers: Gujarati stepwell inscriptions explicitly declare that the water found in them comes from the Ganges. Thus to bathe in a stepwell was to take a ritual bath in that sacred river, and thus to attain the Hindu pilgrim's dream of reaching the sacred city of Varanasi.

Reflection in clear water, Ankol Mata Stepwell, Davad, 11th century

In the heat of the day men rested in the cool pavilions of stepwells, but women were the ones most deeply associated with water. Throughout the region they collected water in a *lhota,* a round-bottomed, short-necked jar with a wide lip that kept the liquid from spilling. They carried the jar, often for long distances, atop a cloth ring that cushioned their heads. (Even today, when most villages have communal water taps, the water must still be carried home.)

But going to the well was not simply an onerous task. Often it was the lone independent activity young women were permitted, and so in fact it was a welcome respite. (To this day in much of India, when a bride moves into the home of her husband's family, she does a good deal of the work.) At least at the stepwell she could laugh and joke and splash with other young women who were equally isolated by the strict patriarchy that prevailed in much of South Asia.

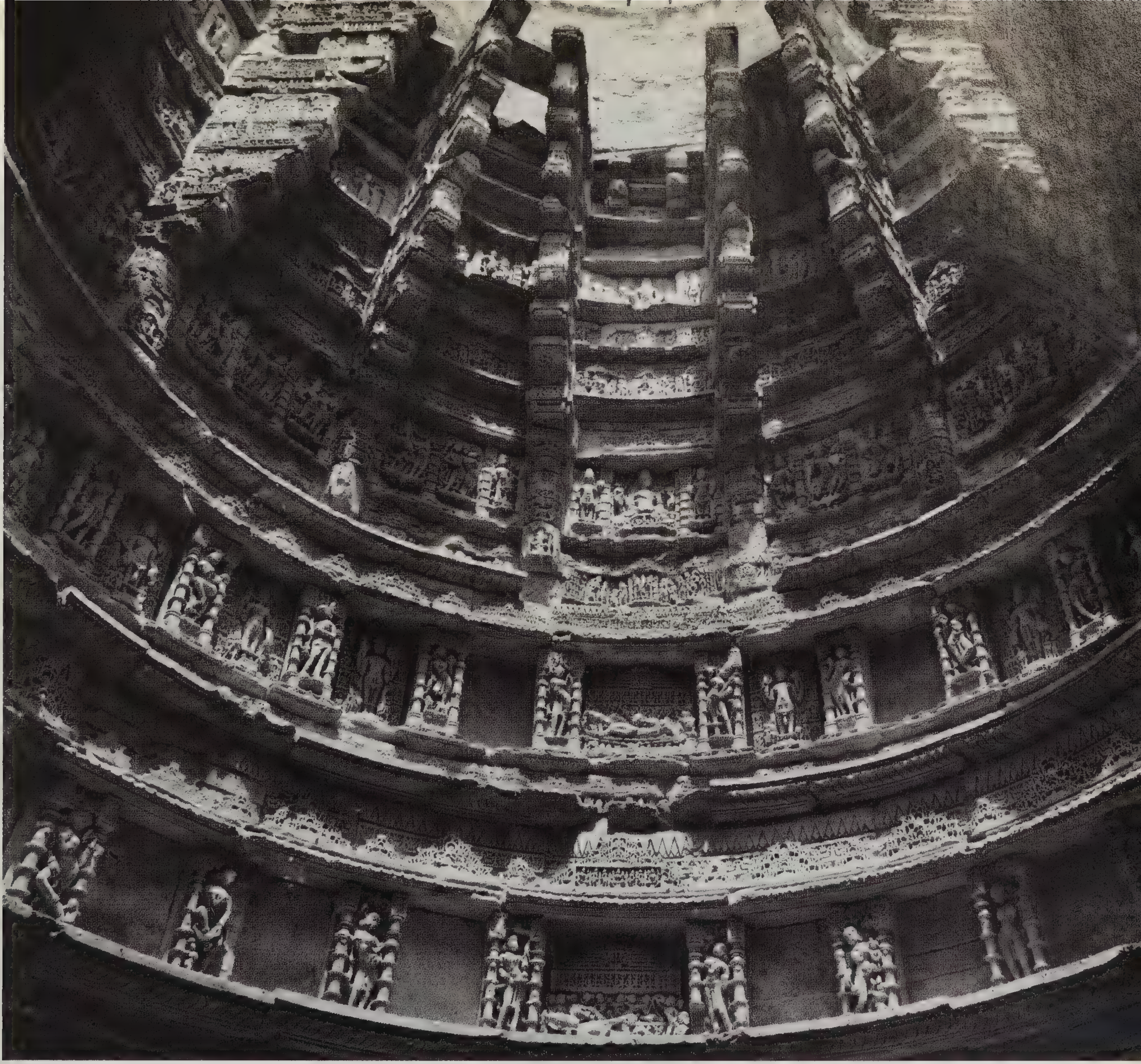
Women also frequented stepwells as an indirect consequence of a Hindu doctrine holding married women solely responsible for the gender of their children. As is still the case today, women remained low in the family hierarchy until they gave birth to a boy, and so even unmarried girls performed rituals intended to make them mothers of men.

Going to the well was often the lone independent activity permitted to young women.

For both girls and women embedded in this set of beliefs, one of the few comforting acts was to beg for help from the mother goddess, Devi, who lived in every stepwell. They could worship Devi by bathing—for water is believed to be one of the forms the goddess takes—or by invoking her name while pouring water over their heads. Not surprisingly, then, most stepwells included shrines to Devi, adorned with garlands of fresh flowers, strips of silk, oil lamps, incense, jewelry, and vermilion pigment. Women even sprinkled milk on the walls around the shrine and on the parapet surrounding the top of the well—in hopes that their symbolic act would bring them plenty of good breast milk for their children [*see photograph at top of page 56*]. The mother goddess is central to women's lives, and the term *Mata,* or Mother, figures in the names of perhaps a third of the stepwells—Mata Bhavani, Matri Mata, Bhadrakali Mata.

Women born into the lower castes, however, were excluded from the stepwells. Traditionally, all low-caste individuals would have obtained drinking water from muddy pools near the boundary of a village—unless someone from a higher caste drew it for them as an act of charity. Such restrictions on access to a nominally public water source throw into sharp relief the age-old contradictions between the demands of doctrine and the necessities of life.

Religious differences—generally such an explosive and destructive issue—played a creative role in the development of the stepwell. Beginning in the mid-eighth century, Muslims began to wrest control of various Hindu kingdoms through many small conquests. By the end of the twelfth century, Muslim sultans had come to ascen-



Seeing the sky from four stories down: The Rani ki Vav, or Queen's Stepwell, Patan, late 11th century

dancy in Gujarat, marking the onset of many centuries of Islamic power in the region—and the end of the glory days of the Hindu stepwell. By the early fifteenth century India's medieval Hindu kingdoms had largely dissolved. Yet the stepwell itself lived on.

India's Muslims were cosmopolitan people, more interested in politics, war, and trade than in agriculture; their soldiers operated under a mandate, amounting to a religious injunction, never to harm a stepwell, even in war. The Muslims brought to India the secular, social traditions of the *hamam,* or bathhouse, and the geometric, nonfigurative traditions of Islamic ornamentation. In 1411 the sultans established Ahmadabad as their first Indian capital; soon afterward they built a series of elegant stepwells nearby. Among them are Queen Rudabai's Stepwell at Adalaj and the Ambapur Stepwell at Budthal, the most majestic ever built.

It was only with the British rise to power in India in the early nineteenth century, that opposition to stepwells as key elements of the Indian water system emerged. To the British, stepwells were a sanitary disaster. The installation of rural taps became a top priority of the Raj. Not without reason, the British colonialists feared disease from the mixing of bathing and drinking water; moreover, the stepwells hosted a waterborne parasite, the guinea worm.

Postcolonial, independent India continued the

Walls surrounding shrines to Devi, the mother goddess, are often white with dried milk.

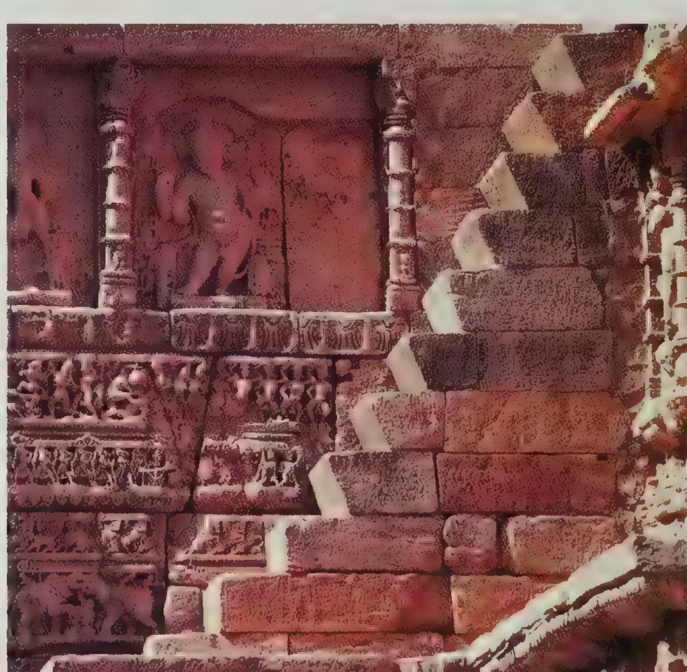
British policy of promoting taps instead of stepwells. But to bring water to those taps, the Indian government embarked on the construction of gargantuan dams. Partly by accident and partly by design, those projects have helped cause the destruction of an important but unsung component of the medieval water system: the many thousands of earth-walled dams that slowed the monsoon runoff, protecting topsoil and giving rainwater time to seep into the ground and replenish the aquifers. As for the stepwells themselves, some became repositories for trash and old tires, a few became the basements of new buildings, others became latrines. In Mehmadabad, Gujarat, a large apartment block collapsed into a stepwell near the market. Yet scores of wells remain usable. Gujarat's stepwells rode out a magnitude 7.6 earthquake that struck the Indian state on January 26, 2001; their large, flat stones, superbly joined and weighted down by the stones above them, are hard to rock [*see "Shaken to the Core," by Susan Hough and Roger Bilham, February 2003*]. Much more destructive to the stepwells in the long run have been powerful pumps and increased irrigation, both of which can lower the water table until a stepwell no longer reaches it, or until salt, saltpeter, or petroleum contaminate the water, permanently ruining its taste. Today the once-wholesome water—proclaimed by some of the inscriptions in the stepwells to be "as sweet as milk"—is just a memory.

Nowadays the consensus is that, once upon a time, stepwells were a fine thing. Villagers still look upon them fondly, not as water wells but as open, public spaces. No longer interested in drinking from them or bathing in them, the villagers are repossessing and rehabilitating them as homes for Devi. They ornament the stepwell shrines to the goddess in much the same colorful way as they decorate their own homes for festivals, imbuing otherwise austere, monochrome stepwell entrances with a festival air.

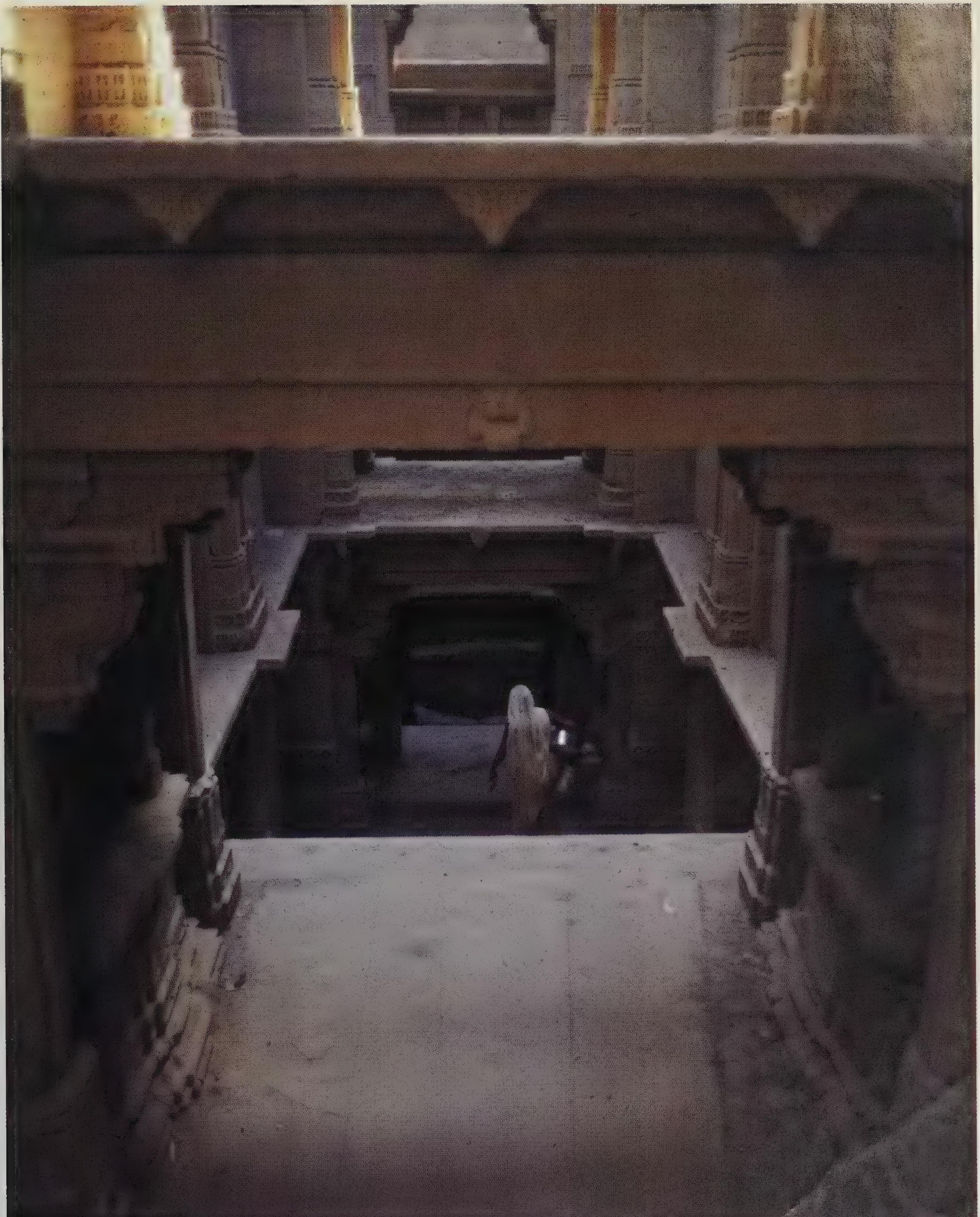
At the same time, historians and preservationists have begun to recognize the value of stepwells as superb works of architecture, ancient monuments that deserve to be left intact and be protected. Their potential for tourism, moreover, has not gone unnoticed by the government: officials from the Archaeological Survey of India have begun to charge admission. Those "official" uses, of course, run head-on into conflict with the more exuberant ways that villagers have been incorporating the buildings into their own popular culture.

A newly adopted stepwell is quickly embellished with welded metal—considered, in all its forms, a symbol of status. The government leans toward installing metal fences, gates, and tollbooths, whereas the villagers prefer shrine doors, turnstiles, handrails, and occasionally a pergola. The government's color choice is gray or rust, and its additions always have a lock and key; the village work is multicolored and does not prevent entry. Even when electricity is installed, it conveys the differences in cultural perspective: near government stepwells it lights a toll booth; at village stepwells it enables the locals to see the goddess more clearly.

Regardless of which patron gains the upper hand, though, none is likely to reintroduce the stepwell as a way to mitigate the chronic water shortages that continue to plague this part of the Indian subcontinent. Disputes over water rights in the dry season have become almost daily news. Today the stepwells are more like footnotes to a missing text—a vanishing way of life—than solutions to the water problem. What they offer the modern age is their beauty, their solidity, and the intelligence of their engineering, all of which speak volumes about how people were once willing to match their demands to the renewable capacities of the planet. □



Secondary staircase in the Rani ki Vav



Stairway to the water at Narayan Rao Stepwell in Idar, also in the state of Gujarat, India

Bogs and Burning Woods

Small variations in elevation create the strange habitats of New Jersey's pine barrens.

By Robert H. Mohlenbrock

At frequent intervals between 135 million and five million years ago, the sea covered what is now the coastal plain of New Jersey, depositing clays, silts, sands, and gravels. The sandy soil covering the plain today is acidic and low in fertility; it also retains little water, creating arid conditions that give rise to fires. Most plants cannot survive in such a hostile environment, but the ones that do make up a distinctive forest called the pine barrens.

Extending as far inland as fifty miles, the coastal plain comprises two sections. The wide, outer plain gradually rises from the New Jersey coast to a crest of low hills. Beyond that, a narrower but more fertile inner plain slopes down to the bank of the Delaware River. The pine barrens comprises more than 2,000 square miles of the outer coastal plain, about a fourth of the state. Much of it is uninhabited, but because of the acidity of the soil, some zones have been cleared for raising commercial crops of blueberries and cranberries. Here and there towns and villages have also been established. In 1978, concerned that development would obliterate the natural environment, the U.S. Congress designated the area the New Jersey Pinelands, the first so-called national reserve.

The pine barrens terrain is relatively flat, never rising more than 200 feet above sea level. But minor differences in elevation create four identifiable habitats. Highest are two kinds of dry forests, one dominated by pitch pine and one dominated by oaks. Bogs (the third habitat) and cedar swamps (the fourth) occur in the lowlands. All four natural communities appear here and there throughout the national reserve, but large continuous acreages of the pine barrens are also administered by the state: Wharton State Forest, Brendan T. Byrne (formerly Lebanon) State Forest, and Belleplain State Forest.

Historically, fire has helped maintain the dry forests, striking at least once every twenty to forty years (large fires are becoming less frequent, however, because of increased control). The characteristic species are fire tolerant, usually surviving because they have extensive underground root or rhizome systems. In one twenty-square-mile zone of pitch-pine forest, the fires have burned every ten to twenty years, and the pitch pines and associated species grow only four to ten feet tall. Such stands are known as pine plains or dwarf pine forests. East of Brendan T. Byrne State Forest, along State Route 72 just west of its junction with County Road 539, the trees are only a few feet tall. Standing among them, the average adult can feel like a giant.

About seven and a half miles north of the same junction is Webb's Mill Bog, one of my favorite bogs in the pine barrens. It is the most accessible because it is surrounded by a metal walkway. Bogs develop in low depressions where as much as two feet of

Atlantic white cedars inhabit a lowland zone.

Pitch pines, above left, withstand arid conditions. Above right: Curly grass (a fern) grows in Webb's Mill Bog.

standing water collects. Atlantic white cedars scattered amid the other vegetation remain stunted as long as the water is deep, growing no more than four feet tall. As a bog fills in with dead vegetation, including the highly acidic cedar leaves, however, the water becomes increasingly acidic, discouraging the growth of some plant species. At the same time, the area starts to dry out, and the cedars begin to grow straight up as high as seventy-five feet, shading (and thereby stunting or killing) many of the small plants beneath them. The habitat is thus transformed into a cedar swamp.

The pine barrens of New Jersey is the northernmost range of 109 southern plant species. Among them are turkey beard, golden-crest, and yellow asphodel. Botanists have also discovered fourteen species of plants more common farther north that reach their southernmost limit in the pine barrens. Rarest and most unexpected of those are broom crowberry, a wiry shrub with crowded, quarter-inch-long leaves and black berries, and curly grass, a fern that has small curly leaves that look like immature grass.

HABITATS

Pitch-pine forest Made up primarily of pitch pine or a mixture of pitch pine and shortleaf pine, this kind of forest often includes a few broad-leaved trees, particularly blackjack oak, post oak, and chinquapin oak. Several low-growing shrubs, such as lowbush blueberry and black huckleberry, are common. The few non-woody species include little bluestem, wintergreen, Virginia tephrosia, wild indigo, tall oatgrass, cowwheat, low frost weed, turkey beard, and bracken fern.

Oak forest Scarlet oak, white oak, black oak, and chestnut oak prevail in the canopy; pitch pine is a secondary species. Other trees are blackjack oak, post oak, and sassafras. The shrub layer includes lowbush blueberry, black huckleberry, dangleberry, staggerbush, inkberry, and sheep laurel. The forest floor is home to the same species that grow in pitch-pine forests.

Dwarf-pine forest Pitch pine is the main tree, but blackjack oak, bear oak, and chestnut oak are also common. Shrubs include broom crowberry, mountain laurel, sheep laurel, sand myrtle, golden heather, black huckleberry, and lowbush blueberry. Other species include trailing arbutus, bearberry, wintergreen, inkberry, sweet fern, flowering pixie moss, and cowwheat.

Bogs Interspersed with stunted Atlantic white cedars are hummocks bearing purple pitcher plant, three kinds of sundews, tuberous grasspink, snakemouth orchid, racemed milkwort, golden-crest, a pink Saint-John's-wort, and two creeping species of wild cranberry. A large, yellow-flowered bladderwort sends stems several inches above the surface of the water, and the yellow asphodel is spectacular in late June and early July. Here and there are patches of American white water lily and Engelmann's arrowhead. The curly grass fern can be found curled up on mounds of sphagnum.

Cedar Swamp Although the principal tree is Atlantic white cedar, the canopy also includes red maple, sweet bay magnolia, gray birch, and black gum. Coastal sweet pepperbush, highbush blueberry, and swamp azalea are the predominant shrubs. Beneath the woody plants grow netted chain fern, cinnamon fern, sensitive fern, and various sedges and rushes.

For visitor information, contact:
Wharton State Forest
4110 Nesco Road
Hammonton, NJ 08037
609-561-0024
www.state.nj.us/dep/forestry/parks

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REVIEW

Hydro Dynamics

Forget oil. Sharing freshwater equitably poses political conundrums as explosive and far-reaching as global climate change.

By Sandra Postel

Almost all the water on our planet—more than 97 percent—is undrinkably salty. Of the remainder, more than two-thirds is locked up in glaciers and ice caps. Only a minute share of Earth's water, less than one-hundredth of 1 percent, is both fresh and renewed each year—a total of 110,300 cubic kilometers of freshwater that circulates annually among the sea, air, and land in an endless cycle, driven by the Sun. After it falls as rain or snow, much of this water returns to the atmosphere through evaporation, or by transpiration from plants. Only a bit more than a third of the total, about 40,700 cubic kilometers a year, runs back to the sea via rivers, streams, and underground aquifers.

That portion of a portion is all the runoff available for irrigating crops, powering turbines, supporting industries, and quenching people's thirst. It also sustains fish and other aquatic life, dilutes pollution, moves sediment to deltas, delivers nutrients to productive coastal estuaries, and performs a host of other ecological jobs collectively worth hundreds of billions of dollars a year. Freshwater is therefore much more than a strategic resource such as oil or uranium; it is a fundamental life support, and the part of it that people can sustainably access is much smaller than all the blue on a world map would suggest.

In fact, freshwater is a uniquely important resource because, for most of its uses, it is not replaceable by any other substance. And, unlike most resources, it does not stand still until people come along to mine it or move it. Water flows naturally across national and other political boundaries, creating unique political problems. Those problems are only going to increase. By 2025 some three billion people will live in places where it will be difficult or impossible to get enough freshwater to satisfy all of their industrial, food, and household needs. In their different ways, the new books by Robert Kandel and Diane Raines Ward each offer a useful perspective on this fact of life in the twenty-first century: the world is entering an unprecedented period of water stress.

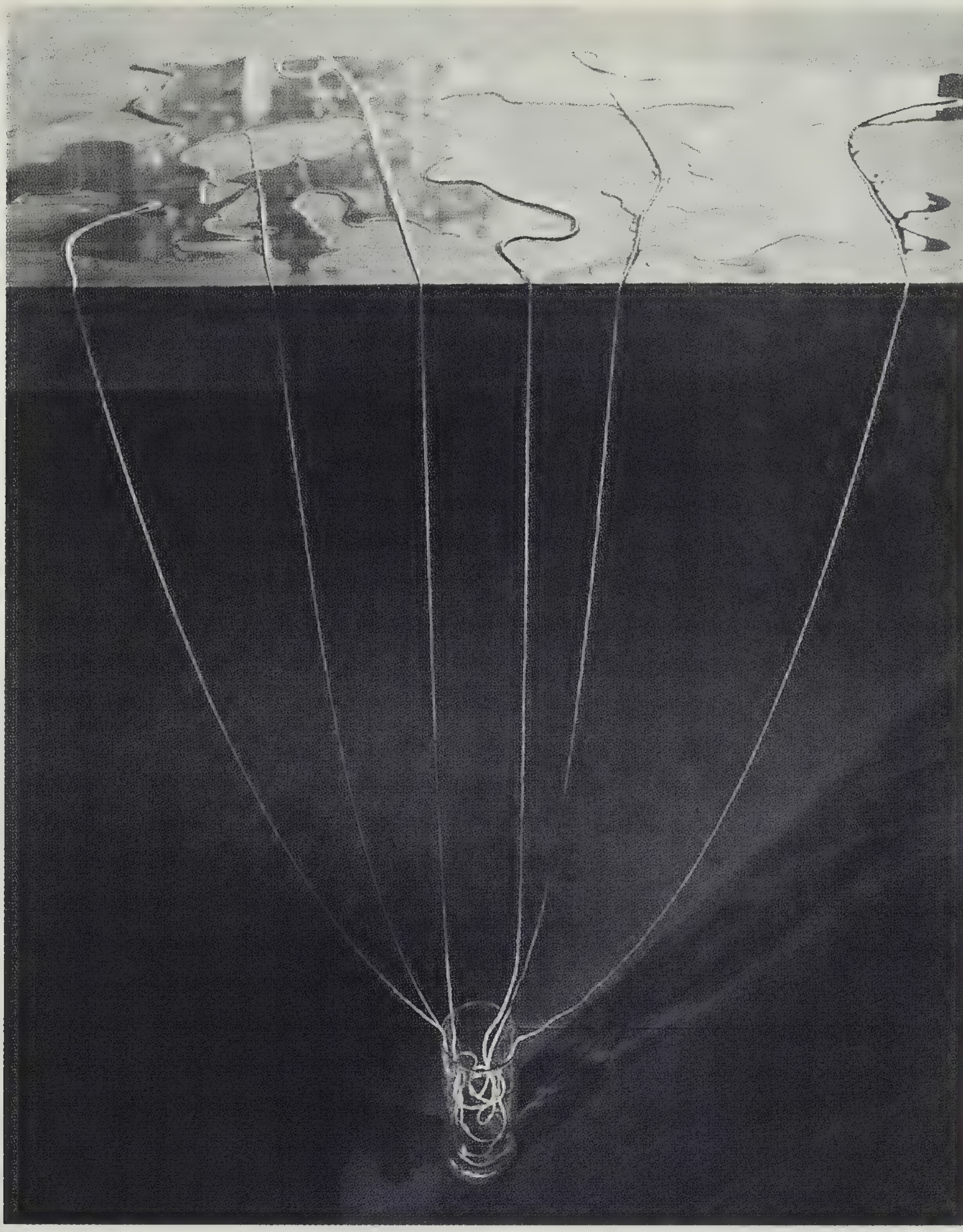
Water from Heaven: The Story of Water from the Big Bang to the Rise of Civilization, and Beyond
by Robert Kandel
Columbia University Press, 2003; $27.95

Water Wars: Drought, Flood, Folly, and the Politics of Thirst
by Diana Raines Ward
Riverhead Books, 2002; $24.95

The Tigris-Euphrates river basin, that all-too-familiar geopolitical hot spot, gives a hint of things to come. The Euphrates River originates, like the Tigris, in the mountains of eastern Turkey; it then flows southward through Syria and Iraq before emptying into the Persian Gulf. In January 1990 Turkey flexed its water muscle in a big new way: it stopped the Euphrates from flowing into Syria and Iraq for a month in order to fill the reservoir behind the Ataturk Dam, the centerpiece of a massive irrigation and hydropower scheme in Turkey's impoverished southeastern region.

Turkey had warned its downstream neighbors the preceding November that it would soon start filling the reservoir, and offered to increase river flows for several weeks so that the two countries could store additional supplies beforehand. Instead, Syria and Iraq protested the river stoppage. Turgut Ozal, then president of Turkey, promised his neighbors that his nation would never use its control of the river to "coerce or threaten them," an assurance that undoubtedly rang hollow, given his government's veiled threat just a few months earlier to cut the Euphrates' flow because of Syria's support of Kurdish insurgents. (In fact, the perpetual lack of agreement between the two nations on water was reported to be part of Syria's motive for helping the Kurdish separatists in the first place.)

The Ataturk Dam was just the beginning. Turkey's $32 billion Southeastern Anatolia Project includes twenty-two dams on the Euphrates and Tigris Rivers, the irrigation of 4.2 million acres of land (an area larger than the state of Connecticut), and the generation of 27 billion kilowatt-hours of electricity annually. At full scale the project could reduce the Euphrates' flow into Syria by 35 percent in normal years and by substantially more in dry ones—not to mention polluting the river downstream with



David Goldes, *Collecting water from table,* 2002

salts and chemicals. Iraq, third in line for Euphrates water, would see a drop as well. Those two rivers, the fluid backbone of the ancient Sumerian, Assyrian, and Babylonian civilizations, are in for a colossal change—and so are the region's politics.

The same unfolding story line is being played out, with different actors and at different intensities, in many other parts of the world—including the U.S. Southwest, southern Africa, the basin of Central Asia's Aral Sea, and the Nile and Jordan river basins, to name a few. Most of the planet's large rivers, in fact, are already controlled by *Homo sapiens,* not by nature. A river has a distinctive pattern of high and low flows, a flow signature that reflects the climate, geology, vegetation, and other natural features of its watershed. Through the seasons of the year and over the decades, those natural variations have created the habitat conditions to which the life within that river system has adapted. Floods cue fish to spawn, for instance, and trigger certain insects to begin a new phase in their life cycles. Floods also bring seasons of life to a river's floodplain, creating habitats crucial to the breeding and feeding of fish, waterfowl, and other river-dependent species. Yet with our dams, reservoirs, and diversion canals, we human beings have dramatically altered the quantity and timing of natural river flows. It will take the best of science, technology, management, and ethical awareness to figure out how to meet the water and food needs of the burgeoning human population while leaving enough for nature's needs.

In *Water from Heaven,* Kandel, a senior scientist with the French National Scientific Research Agency, begins at the beginning. He takes us

all the way back to the big bang and through the creation of our solar system. He explains in fascinating detail the origins of water on planet Earth and how the molecules of water have circulated throughout time.

Liquid water has been on our planet for at least three billion years. Nowadays the stock of water is fixed (though there may be "cosmic snowballs"—small comets made of water—that smash into the Earth and so add to the planet's water supply). Water moves in closed cycles that operate over vastly different scales of time and space.

Some water molecules are trapped deep within the Earth and remain there for millions of years, then burst suddenly into the atmosphere through an erupting volcano. Others stay close to Earth's surface, changing back and forth from liquid to vapor to liquid again as they move from sea to air to land and back to the sea. There are water molecules that reside for millennia in deep underground aquifers—until, perhaps, some desert agriculturalist pumps them up to irrigate thirsty crops. And there are water molecules trapped in glaciers and mountain snowpacks for many decades, released only when they melt into rivers that flow toward the sea. "Whenever you eat an apple or drink a glass of wine," Kandel explains,

> you are absorbing water that has cycled through the atmosphere thousands of times since you were born. But you are also absorbing some water molecules that have only been out in the open air for a few days or weeks, after tens or hundreds of millions of years beneath the Earth's crust.

The morphing of technological accomplishment into potential disaster is a recurring theme in Ward's account of large-scale water projects.

One might think such an impressive history would engender a sense of awe and respect for nature's water cycles. Instead, we take it all for granted. For the past several thousand years people have altered those cycles in innumerable ways to satisfy their needs and wants.

The earliest to do so on a substantial scale were probably the Sumerians, who migrated out of the Mesopotamian highlands some 5,500 years ago and settled in the Fertile Crescent's lowland plains (present-day southern Iraq). Their new climate was sunnier, and kinder to their crops, but it lacked rainfall at critical times during the growing season. So they built canals to siphon water from the Euphrates River and transport it to their fields, giving rise to the world's first irrigation-based society.

Unfortunately, the Sumerians were also among the first to experience the scourge of salinization—salt accumulation as a result of the evaporation and transpiration of irrigation water. (Even today, one out of five acres of irrigated land suffers from the buildup of salts in the soil.) Ancient Mesopotamia also sustained the earliest, and some would say the only true, water war—a battle some 4,500 years ago between the city-states of Lagash and Umma.

So the patterns of modern water-related threats to both agricultural sustainability and regional peace were already unfolding thousands of years ago. But only within the past century, and particularly within the past fifty years, has the scale of human impacts on the Earth's water cycles and freshwater systems reached global proportions. By 1950, civil engineers had constructed some 5,000 dams higher than fifty feet on rivers around the world. Today such large dams number some 45,000. On average throughout the world, people have

built two large dams a day, every day, for the past half century.

That monumental scale of water development and the drudgery and disease suffered daily by the 1.1 billion people who still lack safe drinking water are what preoccupy Diane Raines Ward, a writer based in New York City. Ward's interest in water politics stems from interviews she conducted for the international edition of *Newsweek* in the late 1980s in Turkey, where she first learned about the Southeastern Anatolia Project. In *Water Wars* she takes the reader on a whirlwind tour of big-dam projects, large irrigation schemes, and potential flashpoints of water tensions around the world. Her superb storytelling, enriched by scores of fascinating interviews, more than makes up for what the book lacks in analytical exactitude.

Ward illuminates the promise and pitfalls of large-scale water development with stories from Australia, Brazil, China, India, Pakistan, Turkey, and the United States. She describes in some detail the Tennessee Valley Authority (TVA), which carried out one of the earliest big-dam development schemes and became a model for many that came later. Even today, engineers in India and Pakistan proudly state that the vast engineering works of the Indus River basin, which include the largest contiguous irrigation scheme in the world, drew on the TVA's approach.

Yet the unsustainability of many of those large schemes is increasingly apparent. In the Indus basin, heavy diversions of river water, overpumping of groundwater, and, most important, soil salinization pose serious threats to farm productivity in the coming decades. The morphing of technological accomplishment into unthinkable potential disaster is a recurring theme of Ward's account: "We began the mighty engineering works of the twentieth century in environmental ignorance," she writes, "and ended the century in environmental crisis."

In spite of the title of Ward's book, relatively little space is devoted to water wars in the conventional sense of that term. Both Ward and Kandel confine their discussions of modern hydropolitics largely to the Jordan, Nile, and Tigris-Euphrates river basins.

Perhaps, though, they have good reason to limit and so sharpen their focus: in none of these hot spots of water dispute is there yet a basin-wide treaty that clearly and fairly allocates the available water among all the parties. Thanks to lands acquired during the Arab-Israeli wars, Israel controls the lion's share of the water in the Jordan basin, including important reserves of groundwater under the West Bank. Because Israel's per capita water use far exceeds that of its neighbors (even in the occupied territories, Israeli settlers consume about five times more water per capita than the Palestinians do), any hope for lasting peace in the region will have to include a more equitable apportionment.

As for the Euphrates, Syria and Iraq

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have had an agreement since 1990 to share the flow that crosses the Turkish-Syrian border; so far, that has amounted to about half the average annual natural flow of the river. Turkey, however, has only a temporary agreement with Syria, and has had no serious negotiations with Iraq for more than a decade—effectively ignoring the two downstream nations' calls for a final settlement of their water dispute. Turkey was just one of three countries (along with China and Burundi) to vote against a 1997 United Nations convention that established two key principles to guide international water-sharing: first, the idea of "equitable and reasonable use" and, second, the obligation not to cause "significant harm" to one's neighbors.

Turkey apparently has different ideas about water-sharing. In response to Syria's 1992 requests for more Euphrates River water, Suleyman Demirel, then Turkey's prime minister, reportedly remarked, "We don't say we share their oil resources. They can't say they share our water resources." Turkey does, however, want to sell some of its water. There is a plan to export water from another river, the Manavgat, to Israel—an idea the Israeli government has recently warmed to.

In the years ahead tensions over water may flare in regions outside the Middle East as well. Worldwide, there are 261 rivers shared by two or more countries, yet in most of those river basins there is no treaty that divides the water equitably among all the parties. In more than twenty of them, disputes could erupt or intensify in the next decade, as nations decide unilaterally to begin constructing large dams and water projects—just as Egypt, Israel, and Turkey have done in their respective basins. Countries whose water flows are disrupted would end up suffering from reduced agricultural potential, urban and industrial water shortages, and environmental degradation; in the worst cases, water shortages could spark the flight of ecological refugees, or cause similar humanitarian disasters.

River basins to watch include the Mekong and Salween in Southeast Asia; the Kura-Araks in western Asia; and six basins in southern Africa, including the Incomati, Okavango, and Zambezi. Although countries in some of those basins are building stronger institutions to promote cooperation over their shared waters, most of them have a long way to go.

As if sharing water with each other will not be arduous enough, we must also share water with nature. The same fixed supply supports hundreds of thousands of other species, as well as the ecosystems on which our economies depend—a theme neither Kandel's book nor Ward's adequately addresses. Meeting that challenge is likely to dominate water management in this century just as much as the problem of climate change.

In the past decade investigators have amassed a large body of evidence that the modification of river flows is driving many species to extinction and disrupting natural cycles of great value to human activities. At least 20 percent of the Earth's 10,000 freshwater fish species are now endangered, threatened with extinction, or already extinct. The prospects for the estimated 100,000 species of invertebrates and the thousands of species of algae, bacteria, and protozoa that live in freshwater sediments are uncertain, but biologists have no doubt that these organisms are extremely sensitive to shifting water levels, flow magnitudes, and other hydrologic alterations.

Water shortages could spark the flight of ecological refugees, or cause similar humanitarian disasters.

Each species plays a role in the web

of life that keeps the biosphere functioning. Through Kandel's long lens of geologic time, the loss of species and changes in natural cycles may not be particularly consequential, but they matter a great deal on the human time scales that affect us and our descendants. Restoring some of the natural flow of rivers—by operating dams differently and even by taking some down—is crucial to the harmonization of human needs with nature's requirements.

Both Kandel and Ward devote only limited space to those issues, and both books (particularly Ward's) could have done a better job of analyzing and setting priorities for the proposed solutions. Reducing the human pressures on the Earth's finite water supplies will require much stronger efforts to conserve and recycle water and to use it more efficiently. For example, by irrigating with drip methods that deliver water directly to the roots of plants, farmers can double or triple their crop yields per unit of water consumed. Personal choices make a difference too: it takes twice as much water to provide the food for the average American's diet as it does to produce a nutritious vegetarian diet.

Ultimately, though, it may take a deeper respect for the beauty and mystery of natural water cycles to prevent us from further manipulating them—to inspire us instead to use our scientific knowledge and technical know-how to live more in harmony with nature, just as our earthly companions do. The story of water on Earth will flow on, with us or without us. But unless we assimilate a bigger dose of ecological wisdom, the human chapter of that story is unlikely to have a happy ending.

Sandra Postel directs the Global Water Policy Project in Amherst, Massachusetts. She is the author of Pillar of Sand: Can the Irrigation Miracle Last? *(W.W. Norton 1999) and coauthor of* Rivers for Life: Managing Water for People and Nature, *which will be published by Island Press this summer.*

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By Robert Anderson

Freshwater doesn't always flow freely (and free of charge) from a tap, and it's probably worth knowing, in these days of uncertainty, just where it comes from and how precious it is. The Web site "Water Science for Schools" (ga.water.usgs.gov/edu/) is a great place to start. Although the U.S. Geological Survey (USGS), which monitors the nation's water resources, created the site for classroom use, anyone with a general question about water will find it answered here.

More intrepid web surfers should click on the site's "Water" link (click on "Links," then, in the listings of "Organizations involved with water," click on "Water," or go to www.sbu.ac.uk/water/index) for a look at Martin Chaplin's "Water structure and behavior." A professor of applied science at London's South Bank University, Chaplin offers his own eclectic collection of "Water related links."

Another USGS site ("Water Watch," at water.usgs.gov/waterwatch/) enables you to check the conditions of current water resources around the country. Play around with the options on the drop-down menus at the top of the page: you can learn where droughts are developing (click on "Drought Watch"); view a map showing stream flows in real time (click on "Real-Time Streamflow"); watch map animations of changing water flow over the course of a month (use the second menu to click on "Map Animation—Day of the Year"). If your community draws its water from under the ground, you may want to explore the descriptions of water resources presented in the "Ground Water Atlas of the United States" (go to capp.water.usgs.gov/gwa and click on "Archive").

For the global perspective, try UNESCO's "Water" site (www.unesco.org/water/). Click on "WWAP" on the list at the left of the page to find out what events are planned through the rest of 2003 to celebrate the "International Year of Freshwater." Those interested in water issues in hot spots such as the Middle East—where allotment becomes increasingly contentious as populations expand—can access the list's "Water Links" to browse by geographic region [*see also "Hydro Dynamics," by Sandra Postel, page 60*]. And for more insight into conflicts and tensions over water

David Goldes, *Vortex #1*, 1995

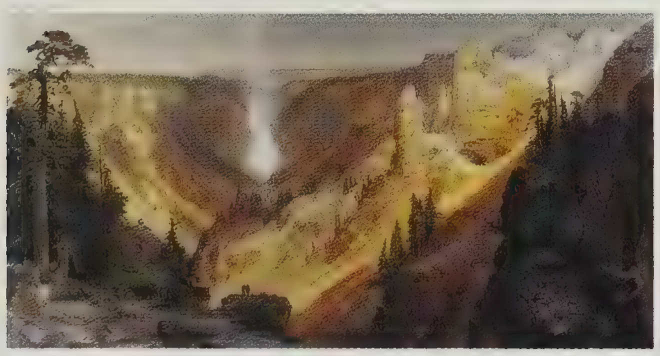
use worldwide, go to "The World's Water" (worldwater.org) and click on "Water Conflict Chronology." I learned there that in 1924 my own water supply, the Los Angeles Valley aqueduct, was the target of bombings by a group opposed to the diversion of water from Owens Valley.

Robert Anderson is a freelance science writer living in Los Angeles.

By Laurence A. Marschall

Hawks Rest: A Season in the Remote Heart of Yellowstone
by Gary Ferguson
National Geographic Adventure Press, 2003; $15.00

Measured by its distance from roads, the Bridger Wilderness, just southeast of Yellowstone National Park, is one of the most remote spots in the lower forty-eight states. It was there, in a small two-room cabin called Hawks Rest, that nature writer Gary Ferguson spent an eventful eleven weeks last year, enjoying the views of Bridger Lake and the sound of the Yellowstone River rushing nearby. The U.S. Forest Service, which hired Ferguson and a friend named LaVoy Tolbert to patch up the place, wound up at the end of the summer with renovated living space, a repaired water supply, and a neatly fenced meadow. More important, lovers of outdoor writing wound up with a rousing and evocative look at the charms and trials of life in the way-out-of-doors.



Thomas Moran, *The Grand Canyon of the Yellowstone*, 1872

But *Hawks Rest* is not your usual idyll about the beauty of untrammeled wilderness. Sure, there are plenty of passages that make you want to head for places such as Fall Creek:

> Dropping 5,000 feet in about five miles. . . . the creek [is] a series of nearly vertical drops broken by icy blue-green pools. The south wall of the canyon is hung with thin waterfalls dropping off the lips of volcanic ledges, while on the north side the streams are more substantial, rocketing off stony chutes, launching themselves into space like kids jumping off their swings.

Surprisingly, though, for a book about the farthest and the wildest, *Hawks Rest* is mostly about people.

To Ferguson's bemusement, Hawks Rest (the place) is plenty trammeled. It's a kind of Grand Central Station of the U.S. outback, a crossroads for all kinds of unlikely characters. Some are eccentrics, such as Lone Eagle Woman, who hikes the woods every summer, communing with the beasts and the trees. Some are trail-worn twenty-somethings from the Forest Service, who turn up to dig out a rockslide, cut back a deadfall, or rescue a stranded hiker. Rangers from neighboring cabin outposts stop by, eager to swap stories of close encounters with grizzlies or—arguably more dangerous—run-ins with poachers and angry hunters.

Many in the passing crowd are professional outfitters, heavy pistols on their belts, wrangling their parties of Eastern dudes who view the out-of-doors as a combination adventure ride-cum-shopping mall for trophy heads. The only times Ferguson and LaVoy are truly alone are when they hike away from Hawks Rest, up to some windswept mountain vista far from the steady traffic of backcountry life.

Where there are people, there is politics—though politics in the wild usually centers on the relations between people (who make policy) and animals (who don't). Often it comes down to the question, Who gets to shoot what and when? So, are the grizzlies treasures or menaces? Have the wolves reintroduced into Yellowstone enhanced its wildness and its balance of predator and prey, or do they pose too great a threat to game animals? Should the Forest Service vigorously discourage the use of salt licks outside of Yellowstone (where hunters take potshots at the elk in exchange for a hefty fee to the outfitters who plant the licks to lure the game)?

Ferguson leans "green" on these issues, a view quite different from that of the gun-toting outfitters and ranchers who derive both income and identity from the wilderness. He tries to be evenhanded, but it's easy to see where his sympathies lie—and if you're well disposed to his engaging and elucidating prose, it's not hard to go along with him. So if you favor color-coordinated Gore-Tex and carry an internal-frame backpack, you'll love this book. But if your gear tends toward canvas and "camo," you'll find Ferguson a bit irritating. In any case, you will get a sharp and ironic sense of what it's like to live in the American outback, twenty-first-century style.

Voyages of Delusion: The Quest for the Northwest Passage
by Glyn Williams
Yale University Press, 2003; $29.95

In this age of technical marvels, when satellite images of the globe are only a mouse click away (see, for instance, terraserver.microsoft.com), it comes as a shock to see how sketchy are the outlines of continents on maps of the 1700s. More than two centuries had passed since Columbus's voyages, but so little of the world had been charted that geography was more a matter of speculation than of science. Western sailors knew about just a few islands in the Pacific, had a passing idea of the location of Australia, and only half-believed the rumors of a giant continent in the remote south and an ice-free ocean around the North Pole (only one of which, of course, turned out to be true).

As for the New World itself, a vast northwestern quadrant remained unexplored. Some maps—if they showed anything at all west of the Great Lakes—placed the "Isle of

California" off the western coast of North America. Others charted Alaska as the largest island in the Aleutian Islands chain.

The speculative European and American geography of the eight-

Boat with corpses of Franklin Expedition, c. 1900

eenth century, according to maritime historian Glyn Williams, was guided by a seductive assumption: an easy, ice-free passage connected the Atlantic and Pacific Oceans. But the evidence was scanty; the vastness of the North American continent hindered overland exploration, and ice seemed to block all the sea routes around the continent to the north.

One exception seemed to be Hudson Bay, accessible from the Atlantic Ocean by a strait that, in a good year, remained open throughout July and August. There was tantalizing evidence that beyond the bay was a passage to the Pacific Ocean. Whales, earnestly believed to have swum from the Pacific, had been sighted along the bay's western shores, and some reports of the height and direction of its tides seemed to indicate its connection to a larger body of water.

If you read those signs optimistically, as did the Irish legislator Arthur Dobbs (an ardent advocate of a Northwest Passage), all you needed was persistence. Follow the indented western shoreline of Hudson Bay and an inlet would soon be found that led, after at most a few hundred miles, into the balmy Pacific. Dobbs, who never came anywhere near Hudson Bay, managed to persuade the British government that his fantasy was a worthwhile enterprise, and two small ships, under the command of Christopher Middleton, set sail in early June 1741. With an optimism typical of the age, they carried orders not only to find the passage but also to negotiate treaties with the "populous Nations" of the Pacific.

Middleton's expedition, and all others to Hudson Bay in the decades that followed, came to naught. Promising inlets always ended abruptly, ships got stuck in the ice, and men froze, starved, and died of scurvy. It was no better for explorers who, trying a different tack, sought the outlet of the Northwest Passage on the Pacific side. James Cook, on his last voyage around the world, followed numerous fjords into the deeply indented Alaskan coast, meeting nothing but frustration.

Williams's history stops in the 1790s, but, as he notes in his final pages, the disastrous Arctic voyages continued for another hundred years. During that time, however, all the poking and prodding had some effect on geographic knowledge. When Lewis and Clark set out to explore the Louisiana Territory in 1803, the true extent of the North American monolith was beginning to appear on maps, and the hope of the mercantile world for a shortcut through the continent had faded. The dream of an open polar sea replaced the dream of a channel through the continent.

It was not until 1906, by drifting for four years among crushing pack ice, that the Norwegian polar explorer Roald Amundsen managed to navigate an arduous northern route from the Atlantic to the Pacific. By then, Arctic travel was regarded as an expensive and heroic stunt, and the search for a Northwest Passage had become a lesson in the folly of wishful thinking.

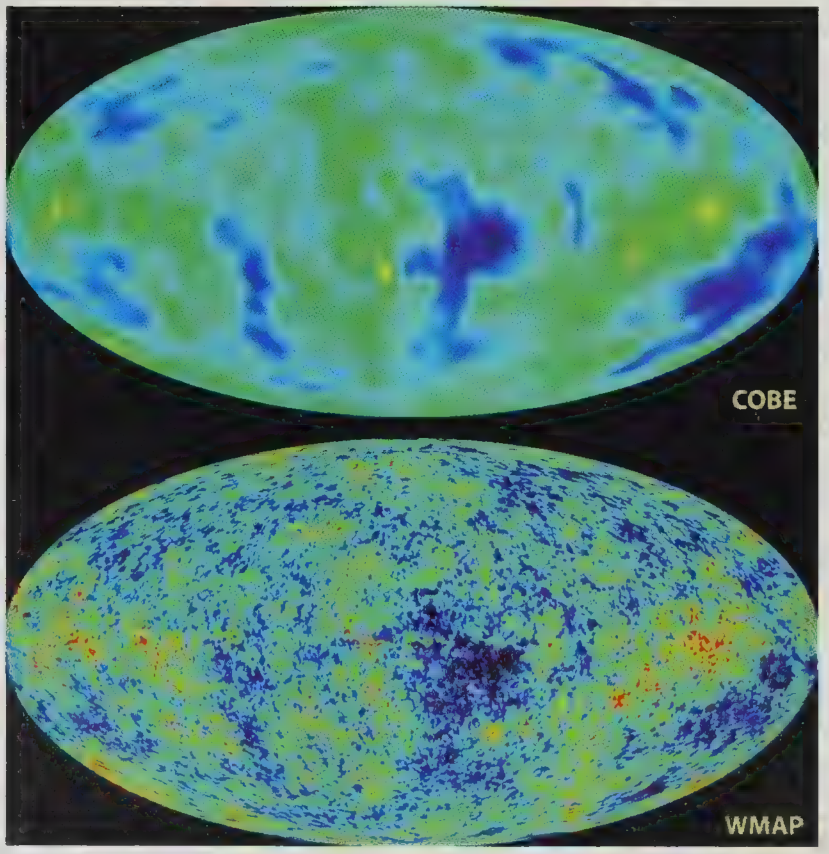
Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

Sharper Focus

Resolving the details of the cosmic microwave background has brought new precision to our picture of the cosmos.

By Charles Liu

For the first third of a million years or so after the big bang, matter and energy in the universe moved in lockstep. Wherever matter was relatively dense, so was energy. Then, as space expanded enough to accommodate the independent motions of material particles and of photons of light energy, the two gradually extricated themselves from their mutual grip. By the end of that process, matter could move and coalesce on its own, forming planets and stars, as well as galaxies, clusters, and superclusters. Light, on the other hand, simply radiated outward in its original configuration, permeating the expanding universe with a warm, omnipresent glow.



Two maps of the cosmic microwave background, which permeates space in all directions, highlight recent improvements in the resolution of satellite observatories that enable astronomers to peer ever more clearly into the origins and fate of the universe. The map by the Cosmic Background Explorer (top), the state-of-the-art observatory just a few years ago, is now far surpassed in detail by the more recent map by the Wilkinson Microwave Anisotropy Probe (bottom).

That glow has steadily faded and cooled ever since, diffusing through ever-expanding space. The temperature of the space-filling radiation (about 3,000 degrees Celsius when light and matter separated) has by now cooled to a frosty 2.7 degrees above absolute zero. And to say the radiation cooled is just another way of saying that the average wavelength of the radiation is no longer fairly short, like the glow of a blast furnace, but much longer, about the same length as the microwaves picked up by an ordinary radio. Astronomers call that radiation the cosmic microwave background, or CMB. In fact, if you tune your radio between two AM stations, about 10 percent of the static you hear is the hiss of the CMB.

In spite of the expansion of the CMB, it has remained otherwise unchanged. By contrast, the structure of the matter in the universe has changed dramatically. The CMB, then, is essentially a partial picture of the universe in its infancy. Not surprisingly, we astronomers have been mapping it for decades, as precisely as our technology allows, hoping to uncover the secrets it has preserved for nearly all of cosmic time.

The results of our latest effort—by the Wilkinson Microwave Anisotropy Probe (WMAP)—made headlines this past February, when cosmologists unveiled the most detailed picture of the CMB ever made. Among all the discoveries reported, one number stood out. WMAP had enabled cosmologists to measure the present age of the universe with unprecedented precision: 13,700,000,000 years.

But what the news reports didn't emphasize was that—though astronomers obviously care how old the universe might be—arriving merely at that number would not have justified all the time, effort, and resources that went into WMAP. Increasingly accurate observational and theoretical efforts to measure and deduce the age of the universe have been going on for a long, long time; one more measurement is, at this point, just one more

measurement. What's really exciting is that the cosmic microwave background hides, within its fossilized patterns of light and dark, evidence of many of the fundamental parameters of the universe—its matter density, its energy density, its rate of expansion, and more. From those parameters, astronomers can infer key details about the earliest moments of the cosmos, and derive a wealth of other properties, including its present age, as well as its geometric curvature and its most likely final fate.

The methods for mapping the CMB were as impressive and sophisticated as one would expect of a multi-year, multimillion-dollar project. The WMAP results were announced February 11, and on that day alone, thirteen papers describing the mission were submitted for publication. Six of those are primarily devoted to the technical details of data extraction. In a nutshell, WMAP scans the sky continuously from the vantage of one of the Earth's Lagrange points [*see "The Five Points of Lagrange," by Neil deGrasse Tyson, April 2002*], mapping patterns of hot and cold in the CMB across the entire sky twice each year. That is no mean feat: the hottest and coldest parts of the CMB differ in temperature by roughly four ten-thousandths of a degree. (That's like measuring sand-size bumps on a perfectly flat living-room floor.)

To achieve that level of precision, WMAP simultaneously measures the CMB temperature of two widely separated patches of sky, then subtracts one from the other. The process enables the satellite to cancel out any contaminating background signals and to map the sizes and shapes of the CMB's hot and cold patches with the highest possible contrast. The ultimate goal is to determine the direct imprint of the structure of the nascent universe on the CMB.

So what's the bottom line? Before the WMAP results, the general scientific consensus was that the universe was between 11 billion and 15 billion years old. Now, we're pretty sure that the universe is between 13.4 billion and 13.9 billion years old. The increased accuracy of the result is certainly welcome: it's a strong, independent confirmation of previous measurements, and it sinks another strong pillar into the foundation—or is it the firmament?—of modern cosmology. But the measurement doesn't really change any basic scientific conclusions.

And ironically, that's what many of my colleagues feel is WMAP's main contribution: it has confirmed most of what we already suspected about the cosmos, and has lent more precision to what has been a rather inexact science. So, in a way, the really exciting part of this discovery may be that it's hardly exciting at all.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

By Joe Rao

Two "three-star" events draw the eye to the sky this month: a transit of Mercury and a total eclipse of the Moon.

At sunrise on the 7th, properly equipped viewers in parts of the eastern United States and Canada can catch the final minutes of the transit of Mercury—astronomical lingo for the apparent movement of a planet across the solar disk. The event is essentially a solar "eclipse" by a body (either Mercury or Venus) too far from the Earth to blot out the Sun's light.

A transit of Mercury was once a scientific event of the first magnitude—to astronomers, literally worth a trip to the ends of the Earth. Careful observations and timing of the transits helped confirm Einstein's general theory of relativity. Transits of Mercury are pretty rare, too: only fourteen of them will take place this century. Watching this one from the U.S., though, isn't the best option. You won't see it at all unless you're east of a line running from roughly Sault Ste. Marie, Michigan, to Charleston, South Carolina—and even if you are, you'll catch only the closing stages of the event. If you want a better look at the entire show—lasting five hours, nineteen minutes—you should plan on more serious travel: to central and western Asia, the Arctic, central and eastern Africa, or Europe (save for Portugal and western Spain, where the transit is under way at sunrise).

Transits of Mercury cannot be seen with the naked eye. You'll need at least a fifty-power telescope to bring out the "dark dot" of Mercury silhouetted against the Sun's disk. Eye safety is always a prime concern when dealing with the Sun. *Never look directly at the Sun through a telescope!* Rather, hold a white card or screen behind the eyepiece, and you'll see an enlarged image of the Sun's disk projected on the card or screen. Your observing site should have a low horizon just to the north of due east. Check the Sun's rising point a day or two beforehand to make sure no trees or buildings block your view.

When the Sun rises in North America, the planet has already begun its passage across the solar disk. As the duo creeps above the horizon, Mercury should be recognizable near the Sun's upper right limb as a small black dot. The dot will reach the edge of the Sun at 6:29:45 A.M., then take another four and a half minutes to move completely off the Sun's disk.

The mortal moon hath her eclipse endured
—*Shakespeare (Sonnet 107)*

On the night of May 15–16 a total lunar eclipse is visible from start to finish from eastern North America and from all of South America. In most of central Canada and the United States the eclipse is already under way when the Moon rises; over the Pacific Northwest and some parts of western Canada, the Moon rises entirely in the Earth's shadow. Observers in western Europe can see much of the event before moonset and dawn on May 16.

The Moon begins to enter the Earth's outer shadow, or penumbra, at 9:06 P.M. But the penumbra is so faint that it cannot be recognized until just before the Moon enters the Earth's dark central shadow, the umbra. By 9:55 P.M. the Moon appears distinctly smudged or soiled on its lower left edge, even to the most casual observer.

The umbra begins to nibble at the Moon's lower left-hand edge at 10:03 P.M., then slowly engulfs our satellite.

During the total phase the Moon does not usually disappear from view. Although the Earth blocks out all direct sunlight, Earth's atmosphere refracts some of the Sun's rays into the shadow. The blue light of the daytime sky is scattered, but the red light of sunrise and sunset is more penetrating and thus can still shine on the eclipsed Moon. As a result, during the total phase (from 11:14 P.M. until 12:07 A.M.) the Moon should not disappear, but should instead glow with an eerie, coppery hue.

The umbra appears to slide completely off the Moon by 1:18 A.M., and the last vestige of any shadow will probably disappear by 1:30 A.M., leaving the full Moon to shine brightly for the rest of the night (and perhaps give poets the light to work by).

Vain Venus rises in the east about an hour before the Sun, as it has all spring. But the lengthening morning twilight of late spring reduces the planet's visibility this month.

Mars rises in the southeast at about 2:00 A.M. local daylight time on the 1st, shining at zero magnitude. By the end of the month its rise comes more than an hour earlier, bringing it close to the meridian at sunrise. Its brightness at that point is −0.7.

Jupiter, crabby or not, is in the constellation Cancer, the crab. The brightest evening "star," it appears toward the west at sunset, fairly high in the sky, and sets in the west-northwest after midnight.

Saturn clings to the horizon in May. The planet remains low in the west-northwest at dusk early in the month; ultimately, evening twilight renders it invisible. Saturn crosses Orion's club at midmonth.

The Moon is new on the 1st at 8:15 A.M. It waxes to first quarter on the 9th at 7:53 A.M., reaches full on the 15th at 11:36 P.M., and wanes to last quarter on the 22nd at 8:31 P.M. The Moon becomes new again on the 31st at 12:20 A.M. On the same day a ring-shaped, or annular, eclipse of the Sun will be visible from central Greenland and from Iceland and northern Scotland.

Unless otherwise noted, all times are given in Eastern Daylight Time.

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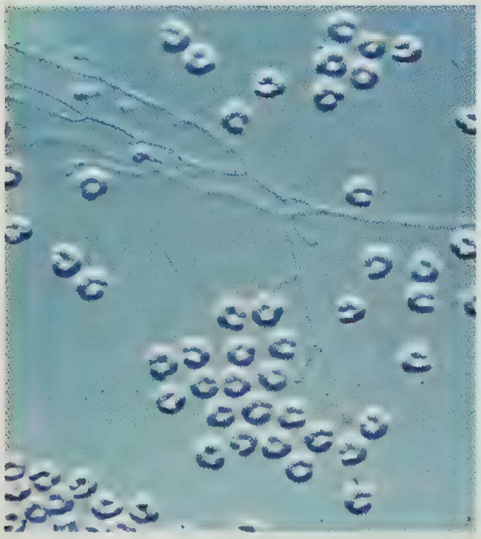
(Continued from page 26)

with nutrient. Both the large hyphae and the three-celled spores that bud from the hyphal ends seem well suited to being eaten, but not to dispersal.

In spite of their large, conspicuous shape, the spores were a mystery to us; none of our reference books on fungi were any help in identifying them. We sent our information and observations to Kris A. Pirozynski, a mycologist who is now retired from the Canadian Museum of Nature in Ottawa. When Pirozynski got our letter, he called us excitedly. The spores were *Delortia palmicola,* he said, but



Three-celled spores of Delortia palmicola

what kind of tree had the wood come from? Could the tree have been a palm? Several times, he told us, he had spotted dried and shriveled remnants of *Delortia* on dead palm trees in East Africa. The fungus, he felt sure, was associated with insects, but he had never found any insect associations himself.

Our observations, together with Pirozynski's identification, began to make sense. The Tiputini collection site was thick with palm trees, so our termites' log was probably from such a plant (unfortunately, the rotten log had been beyond identification ever since Wier first encountered it). The remnants of *D. palmicola* that Pirozynski had included in his East African fungal survey had probably been eaten by termites, too, even though the insects had done so out of his sight.

Then, a routine observation that we overlooked at first suddenly stirred much more of our interest. We checked again several times by removing more hindguts. Our *Heterotermes'* swollen intestines always held wood-digesting protists and myriad bacteria, but we also spotted three-celled *Delortia* spores. Just to be sure, in the laboratory we transferred translucent fungal dots to a medium of cellulose-rich palm-tree extract. The spores that developed on those fungal hyphae were also those of *Delortia.*

Not only had the termites found a way to control the spread of dangerous fungi in their nests; apparently, the insects had also discovered that those fat fungal spores could be used as food.

It is easy to imagine what gave rise to such a state of affairs. Fungi and rain were an ever-present threat to the rainforest ancestors of our population of *H. tenuis.* Only those ancestral termites that could cope with inadvertently eating the fungal intruder would have survived. Perhaps the *Heterotermes* ancestors even derived some benefit from the fungus. *Delortia* might harbor cellulase, an enzyme that breaks down the cellulose in wood. If so, a *Heterotermes* termite that ate *Delortia* would get from the fungus both food—consumable nitrogen, carbon, and other nutrients—and cellulases, to help digest wood.

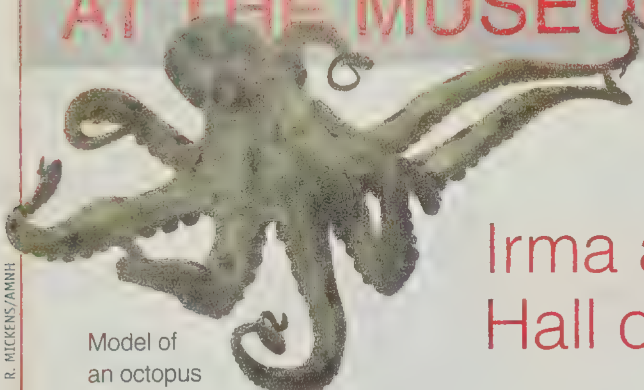
Yet there is no question that, despite the option for casual fungus farming, *H. tenuis* is a lower termite. The presence of certain species of wood-digesting, swimming protists inside *H. tenuis* is a sure sign that the protists digest wood that the termite eats. No doubt, like all of its many *Heterotermes* relatives, our Ecuadorean population can rely entirely on the nutrients digested by the protists. *Heterotermes* termites are not related directly to any of the Old World termites that depend on fungus farming for their food. Evolutionarily speaking, the association between fungus and termite in Ecuador must have begun quite recently.

Thus, we hypothesize, termite agriculture preceded termite cities. The antecedents to higher termites and their termitaria were protist-infested lower termites fighting off heavy rains and encroaching fungi. This defense prompted the growth of palatable dots—masses of fungal hyphae and their spores—on the surface of their resident logs. The activity of *H. tenuis* now makes it clear that termites developed the techniques of fungal culture before mound building evolved. And over time, fungi-tending termites lost their ability to host wood-eating protists. Eventually, some of those became, as the African *Macrotermes* have, completely dependent on their fungi for food.

Today's *H. tenuis* may not be on the road to becoming a protist-free, city-dwelling higher termite. Evolution, after all, is unpredictable in detail. But the insect's behavior in the face of flooding and luxuriant fungal growth must be remarkably similar to that of its Mesozoic ancestors, which did take such a route. Whether the Ecuadorean termites are only analogous, or genuinely homologous, to the lower termites that were the ancestors of the mound builders, we have no idea. But with the discovery of incipient farming in severely threatened *H. tenuis,* one pathway from lower to higher has been happily inferred.

Jessie Gunnard, a candidate for her Master's degree in the Department of Geosciences at the University of Massachusetts in Amherst, hopes to study next fall in the science writing diploma program at the University of California, Santa Cruz. Andrew Wier, a doctoral candidate at the University of Wisconsin–Milwaukee, collects and studies a variety of live bacteria near hot spring vents in Yellowstone Lake. This summer he will dive again in Yellowstone National Park. Lynn Margulis is Distinguished University Professor at the University of Massachusetts in Amherst, where she continues to work out her ideas on the evolution of nucleated cells by symbiosis nearly forty years after she first presented it to fellow biologists and geologists. She is a member of the National Academy of Sciences.

EXPLORER GUIDE



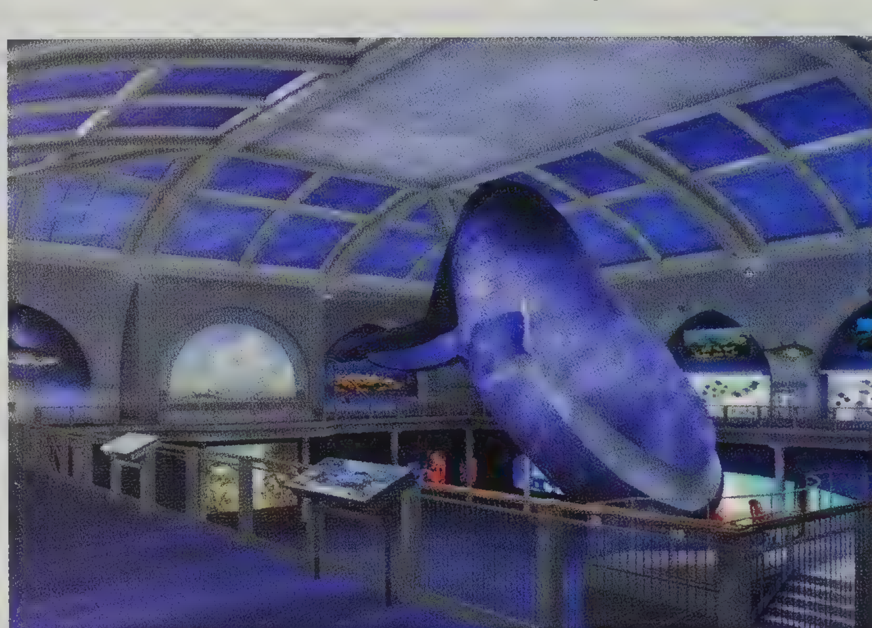
R. MICKENS/AMNH

Model of an octopus

Irma and Paul Milstein Family Hall of Ocean Life Reopens

One of New York City's grandest spaces, the Museum's beloved Hall of Ocean Life, reopens this May after a major renovation, its first in over 30 years. Current scientific research and cutting-edge exhibition technology have been combined with the restored Beaux-Arts elegance.

The 29,000-square-foot hall is still dominated by the famous blue whale, one of the Museum's star attractions, which now floats in a "virtual ocean" created through dramatic lighting, video, and sound effects that include whale songs. The 94-foot female—the largest model of the largest animal on Earth—has been modified to reflect current scientific knowledge of living blue whales. Above the whale, skylights gently illuminated by shimmering blue lights contribute to the illusion of being submerged in the depths of the sea.



ARNOLD IMAGING ©AMNH

Exhibition designers have fabricated over 600 new models, ranging from tiny green bubble algae to a 14-foot-long whale shark to computerized bioluminescent fishes and invertebrates. Joining the renovated ocean dioramas created in the 1930s and 1960s will be an 18 x 8-foot wall of video combining high-definition footage of undersea life, animations, graphics, and an evocative soundtrack that will transport visitors further into the heart of the ocean realm.

The classic dioramas on the lower level have been cleaned and restored, with new lighting brightening areas formerly obscured. In some cases, new backgrounds have been painted from sketches made in the field by exhibition staff. New exhibit text reflects the latest information about the elephant seals on Guadalupe Island, a school of leaping dolphins, and northern sea lions from Alaska's Pribiloff Island, to name just a few.

In particular, the spectacular Andros Coral Reef diorama, the only two-level diorama in North America, underwent a complete overhaul to enhance its visibility. The diorama's upper level, covered for the last 30 years, depicts life above the coral reef. It has been opened for display, repaired and restored, and now offers visitors a breathtaking complete view of the coral reef system below the ocean level and above, a perspective not possible in nature.

The mezzanine level of the hall now features new exhibits on the major ocean ecosystems, including estuaries, mangrove forests, the polar seas, continental shelves, coral reefs, kelp forests, the deep water column, and the deep-sea floor. High-definition video of the ecosystems shot on location around the world combines with explanatory text and newly handcrafted models alongside historical models to depict the tremendous diversity of the Earth's seas and the life therein.

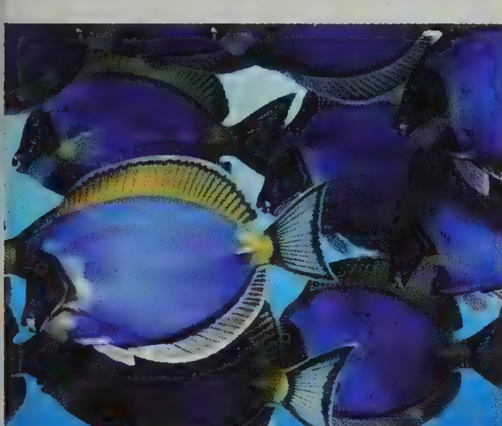
Two new "Spectrum of Life" walls flank the entrance to the hall. They reinforce the idea that all life is connected through an intricate web of evolutionary and ecological relationships. One wall depicts vertebrate life including fishes, reptiles, and amphibians (and even a human), while the other showcases a profusion of invertebrates and plants. Interactive computer stations in front of each wall provide details about the biology and taxonomy of the organisms represented on the wall, as well as information about their "place" in the ocean.

Three of the Museum's classic dioramas depicting life in the oceans of the Ordovician, Permian, and Cretaceous periods—from 450 to 70 million years ago—have been meticulously restored to highlight the history of life in the pri-

mordial oceans. The exhibit features an ancient seafloor slab from the Jurassic Period containing the fossilized remains of a horseshoe crab and the tracks of its last journey. Special panels will showcase several fossil specimens, including cyanobacteria, the first-known life form to emerge in the sea 3.5 billion years ago.

Life on Earth emerged in the oceans and much of it stayed there—scientists estimate that 80 percent of all living organisms may live under water. Over 70 percent of the Earth is covered with water and yet very little is known about the complexity and diversity of life in the oceans. What is known, however, is that the oceans play a vital role in supporting life on Earth. The aim of the renovation of the Milstein Family Hall of Ocean Life is to open a window onto the spectacular ocean ecosystems, to bring current scientific knowledge about the oceans to the public, and to reveal the mysteries and diversity of this, Earth's final frontier.

The Milstein Family Hall of Ocean Life was designed, developed, and produced by the Museum's Exhibition Department. The lead curator is Melanie L. J. Stiassny, Axelrod Research Curator, Division of Vertebrate Zoology, working with a team of cocurators including Mark Siddall, Associate Curator, Division of Invertebrate Zoology; Paula M. Mikkelsen, Assistant Curator, Division of Invertebrate Zoology; Neil H. Landman, Curator, Division of Paleontology; and Robert S. Voss, Associate Curator, Division of Vertebrate Zoology.



R. MICKENS/AMNH

Models of powderblue surgeonfish in the Coral Reef ecosystem exhibit

Milsteins' Gift Makes New Hall a Reality

As dedicated supporters of educational initiatives throughout New York City, Irma and Paul Milstein have been involved with the American Museum of Natural History for over a decade, with Irma joining the Museum's Board of Trustees in 1995. Together, they have generously and enthusiastically supported a number of the Museum's special projects and campaigns as lead benefactors, including the Milstein Hall of Advanced Mammals; the Milstein Family Vertebrate Paleontology Moveable Museum, which some 80,000 children have visited since its launch in 1999; and most recently, the Irma and Paul Milstein Family Hall of Ocean Life.

The Milsteins appreciate the importance of educating people of all ages about the wonders, mysteries, and threats to our planet's oceans. "It has been a wonderfully satisfying experience for the whole family to be associated with the Museum, which we believe is one of New York City's most fabulous educational resources for children and adults. Paul, our 4 children, our 11 grandchildren, and I look forward to the Hall of Ocean Life's reopening and to seeing our planet's largest creature of all time—the blue whale—in its newly beautified home," said Irma Milstein. According to Museum President Ellen V. Futter, "With the help of Irma and Paul Milstein, the Museum was able to bring out the best in one of our most beloved treasures, enlivening the hall for millions of visitors today and for generations to come. The new Milstein Family Hall of Ocean Life places a spotlight on the critical role of ocean ecosystems in maintaining the balance of life on Earth, and educates the public about the last great frontier on Earth—the marine world. We are so very grateful to the Milsteins for enabling us to share the beauty, the science, and the majesty of our 'blue planet,' and for providing such a magnificent model for others who love the Museum."

D. FINNIN/AMNH

Irma and Paul Milstein (second from left and second from right) join Museum President Ellen V. Futter (center) and Vice Presidents David Harvey and Barbara Gunn in the hall.

A project of this magnitude would not have been possible without an extraordinary public-private partnership. The American Museum of Natural History wishes to acknowledge the following donors for enabling us to undertake the magnificent restoration and rejuvenation of the Milstein Family Hall of Ocean Life.

We are enormously grateful to lead benefactors Irma and Paul Milstein, long-standing friends and patrons of the Museum, whose spirited passion for education and our world's oceans launched this historic project.

The Museum gratefully acknowledges the important public support that has been provided by the City of New York, the New York City Council, the Department of Cultural Affairs, and the Borough President of Manhattan in the realization of this project.

The Museum deeply appreciates major support from Edwin Thorne and from Swiss Re.

Significant support also has been provided by The Marc Haas Foundation, Ruth Unterberg, MetLife Foundation, and Mikimoto.

Additional generous funding was provided by Jennifer Smith Huntley, Patricia Stryker Joseph, William H. Kearns Foundation, Denise R. Sobel and Norman K. Keller, Mrs. Frits Markus, Jane and James Moore, David Netto, Mrs. John Ungar, and the Bristol-Myers Squibb Foundation, Inc.

We are also grateful for the funding of educational programs provided by The Atlantic Philanthropies, The Bodman Foundation, and The Louis Calder Foundation.

MUSEUM EVENTS

EXHIBITIONS

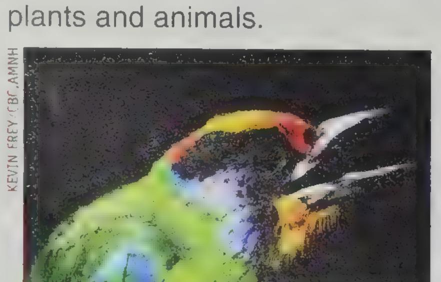
Vietnam:
Journeys of Body, Mind & Spirit
Through January 4, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

C. CHESEK/AMNH

Paper votive goods like these are burned for use by the dead.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the ***Freeman Foundation****. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

Discovering Vietnam's Biodiversity
Through January 4, 2004
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.



KEVIN FREY/CBC/AMNH

Gold-throated barbet, Ngoc Linh, Vietnam

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

Einstein
Through August 10, 2003
Gallery 4, fourth floor
This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

The Butterfly Conservatory
Through May 26, 2003
More than 500 live butterflies fly freely in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.*

LECTURES AND DISCUSSIONS

James Watson on the Double Helix
Thursday, 5/1, 7:00 p.m.
Watson will speak about Francis Crick, the Human Genome Project, and the direction of current research on DNA.

The Fate of the Mammoth: Fossils, Myth, and History
Tuesday, 5/13, 7:00 p.m.
Claudine Cohen considers the history of paleontology through the study of the mammoth.

Vietnam: War and Memory
Wednesday, 5/14, 7:00 p.m.
Panelists share their memories and examine the ways in which the Vietnam War drives their current efforts.

Einstein Papers Project
Monday, 5/19, 7:30 p.m.
A panel discussion on one of the most important scholastic achievements of the 20th century, the publication of Albert Einstein's collected papers.

Vietnamese American Contemporary Arts Roundtable
Monday, 5/19, 7:00 p.m.
Artists present their work and discuss how their experiences as Vietnamese Americans have affected it.

Exposing the Deep: Technology and the Art of Underwater Photography
Thursday, 5/29, 7:00 p.m.
Spectacular 3-D photographs of underwater scenes.

Experience the sights and sounds of a bustling

Vietnamese Marketplace

at the Museum, throughout the run of the *Vietnam* exhibition. Sample traditional foods and take home a one-of-a-kind handicraft.

77TH STREET LOBBY, FIRST FLOOR

FILM SCREENING
The Deserted Valley
Saturday, 5/10, 2:00 p.m.
(In Vietnamese with English subtitles)
Stunning cinematography paired with minimal dialogue eloquently depicts this universal story set in a remote village in Vietnam's highlands. Post-screening discussion.

PERFORMANCES
Starry Nights
Friday, 5/2, 5:30 and 7:00 p.m.
Dave Stryker and Blue to the Bone

ArtSynergy: Finding Connections through Music
Saturday, 5/3, 7:00 p.m.
New works from Kimo Williams and Nguyen Van Nam, followed by a discussion.

Nguyen Dinh Nghia and Family
Sunday, 5/11, 1:30 or 3:30 p.m.
Traditional Vietnamese music.

SPECIAL PROGRAM
Whale Watch 2003
Friday–Sunday, 5/16–18
A weekend expedition with naturalists and educators.

CHILDREN'S PROGRAMS
Paper-Making Workshop
Saturday, 5/10, 12:00 or 3:30 p.m.
(Ages 8 and up)

Journey through the Solar System
Sunday, 5/11, 12:00–1:30 or 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Solar System Adventures
Saturday, 5/17, 1:00–2:30 p.m.
(Ages 7–9)

Undersea Neighbors
Sunday, 5/18, 10:30–11:30 a.m.
(Ages 6–7)

I Want to Be an Astronaut
Sunday, 5/18, 12:00–1:30 p.m.
(Ages 4–6, each child with one adult)

Fly Me to the Moon
Sunday, 5/18, 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Astronaut Susan J. Helms aboard the International Space Station

Humans in Space
Saturday, 5/24, 1:00–3:00 p.m.
(Ages 10–12)

Space Explorers
Eclipses of the Sun and Moon
Tuesday, 5/13, 4:30–5:45 p.m.
(Ages 12 and up)

HAYDEN PLANETARIUM PROGRAMS
Mapping the Universe
Monday, 5/12, 7:30 p.m.
With Brent Tully, Institute for Astronomy, University of Hawaii.

Celestial Highlights
Tuesday, 5/27, 6:30–7:30 p.m.
Find out what's happening in the June sky.

SPACE SHOWS
The Search for Life: Are We Alone?
Narrated by Harrison Ford

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

LARGE-FORMAT FILMS
In the Samuel J. and Ethel LeFrak IMAX® Theater

Coral Reef Adventure
A fantastic underwater journey to document some of the world's largest and most beautiful—and most threatened—reefs.

Pulse: a STOMP Odyssey
Take a rhythmic voyage of discovery around the world of percussion and movement.

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All programs are subject to change.

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Of Mice and Masai

By Richard Milner

After several pairs of house mice determined that my Manhattan flat was a suitable place to raise their families, they gleefully moved in. Rather than scurry furtively along baseboards or hide out until the dead of night, they chased one another in afternoon courtship on my kitchen floor, then brazenly danced up to the table to forage for crumbs. I thought of hantavirus and the Black Plague, yet my first inclinations were kindly: I bought "humane" box traps to capture and relocate my unwanted guests. The next day I found that the mice had taken my bait but had managed not to get humanely caught.

Game board, circa 1885

Inevitably, though, the squeals and pitter-patter of the burgeoning rodent families increased, and I gave in. Reluctantly, I purchased some deadly spring traps "baited" with yellow bits of perforated plastic. None of my little roommates fell for the faux Swiss cheese; the mice went on dancing, dancing, dancing. . . .

Next I bought glue traps, resolving to conk the critters as soon as they were caught. (A slow death in a glue trap, I earnestly believe, should disturb any thinking, feeling person.) I thought of Tom and Jerry, Mickey Mouse, Stuart Little, and Robert Burns's line about "the best laid schemes o' mice and men." Guiltily, I set out the dreadful glue traps, along with a few spring traps for good measure, and went to bed.

Later that night I was awakened by a knock on the door. Two Masai gentlemen stood at my threshold, dressed in their traditional robes.

"*Jambo,*" said one. "Hello. We beg your pardon for the intrusion, sir, but we understand that you are killing animals here."

"What business is that of yours?" I bristled. "You live a world away."

"Yes, sir, but we have come on an urgent mission, to show you how to live with your mice."

"First of all, they're not *my* mice," I replied testily. "I did not invite them. They disturb my sleep, they invade my space, they even defecate near my food. Disgusting. If I don't stop them, they will continue to propagate, carry in fleas and disease, and displace me from my home."

"*Rafiki,*" said the other one. "We come as friends. Your people have been visiting Africa for years, teaching us that we must live with our wild animals, that killing them is not always the correct answer.

"Now we are returning the favor. If you are bothered by squeaks and footfalls in the night, remember that my family must listen to hungry lions roaring nearby at midnight. And believe me, sir, you don't know what it is to have your food soiled until an elephant has relieved himself on your vegetable garden."

Suddenly, he pulled a small video camera from the wide pocket of his robe.

"Do you mind, sir, if I place a bit of cheese on the counter, so I can try to get a sequence of your mice? Most folks back home have never seen the New York City rodents, which are world famous, so I'm making a documentary."

"Look, Otwani," said the other excitedly, pointing to the window. "It's a rock dove, what the locals call a pigeon, just there on that ledge."

The two of them rushed to the window. "My gosh," one shrieked, "I don't believe it—squirrels!" And with that, both ran out of the place, slamming the door behind them. WHAM!

I woke up. One of the traps had sprung.

Richard Milner is an associate in anthropology at the American Museum of Natural History and a contributing editor of this magazine.

Restful Sleep Technology

Get in the zone with the mattress topper that molds to your body's contours

The Memory Foam Ultra mattress topper is cut into a grid pattern combining six different zones for variable support, and a better night's sleep.

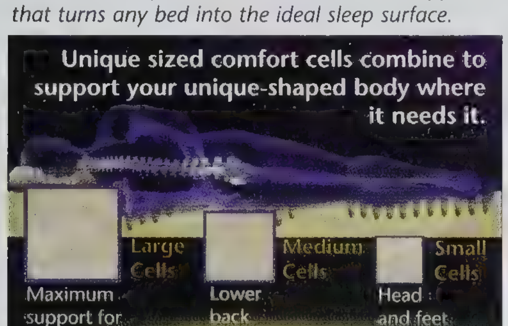
The 2-inch thick temperature-smart foam adjusts to your shape.

It's 3 a.m. You have exactly two hours until you have to get up for work, and you still can't seem to fall asleep. At this point, the phrase "tossing and turning" begins to take on a whole new meaning for people whose mattresses simply aren't giving proper support anymore. Your mattress may dictate your quality of sleep. Even if you merely suspect that your mattress may be outdated, that's when you need to take action. Some mattresses fail to support your spine properly, which can result in increased pressure on certain parts of your body. Other mattresses, sporting certain degrees of visco-elastic foam, can sometimes cost you well over $1000. Now, one of the world's leading manufacturers of foam products has developed an incredibly affordable mattress topper that can actually change the way you sleep. Introducing the future of a better night's sleep: The Memory Foam Ultra Mattress Topper.

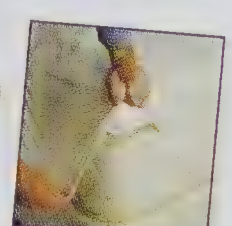
Wake up to a better morning. The Memory Foam Ultra mattress topper is designed to give you a better sleep surface. Not only does it support each region of your body, but it's also temperature sensitive. With its various-sized "comfort cells," the 2-inch thick Memory Foam Ultra mattress topper combines six zones to support specific body area weight, which promotes a better night's sleep. The largest cells support your lower back and midsection, while the medium-sized cells support the shoulders, lower back and legs. The smallest cells support your head and feet. Combined, these zones provide variable support from head to toe. By using visco-elastic foam, the Memory Foam Ultra mattress topper also molds to your body contours to help prevent tossing and turning during the night. When you lie down on this amazing material, the heat and pressure sensitive foam reacts to your body's weight and temperature, so that it molds to your exact body shape. This means that whether you sleep on your back, stomach or side, your weight is evenly distributed and your spine remains in a neutral position. Other surfaces support your body at the shoulders, hips and legs only. This causes your spine to sag in other areas, which can often result in discomfort, and even back pain. You'll wake up rested, relaxed and ready to take on the day. Anyone who suffers from insomnia and back pain can benefit from this technology.

What could be wrong with your present bed?

The ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind Memory Foam Ultra, the mattress topper that turns any bed into the ideal sleep surface.



FREE heavyweight mattress pad included



Included with the Memory Foam Ultra mattress topper is a fitted mattress pad. It's heavyweight and quilted, and made of 200-count 100% cotton with a 15-inch deep fitted spandex skirt to fit a mattress up to 21 inches thick. The size of the mattress pad is determined by the size mattress topper you order.

Try it for yourself today! The Memory Foam Ultra mattress topper can change the way you sleep. Promote proper spine positioning, while enjoying relief from insomnia and back pain with this full-body support. It comes with a five-year manufacturer's limited warranty and TechnoScout's exclusive in-home trial. If you are not completely satisfied, simply return it within 30 days for the full purchase price, less shipping and handling.

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NATURAL HISTORY

6/03

PATTERNS IN NATURE


Ellis Marsalis is considered one of the world's premier jazz pianists.
He's taught some of the world's most famous musicians. Even fathered a few of his own. But with retirement approaching, he didn't want to improvise. Not when it came to money. We worked with him on ways to make the most of his retirement plan, so money wouldn't get in the way of his music. Now he's ready for the next act, whatever that may be.
Log on for ideas, advice, and results. TIAA-CREF.org or call 800.842.1924
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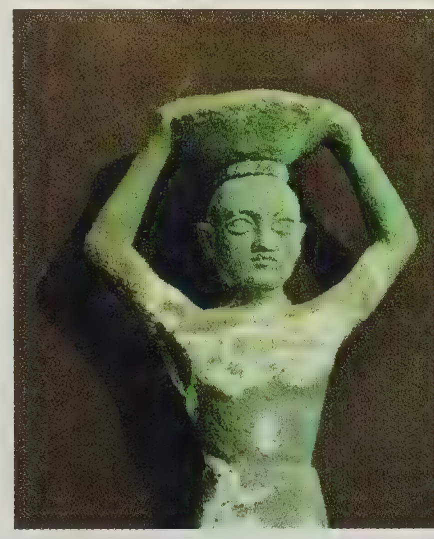
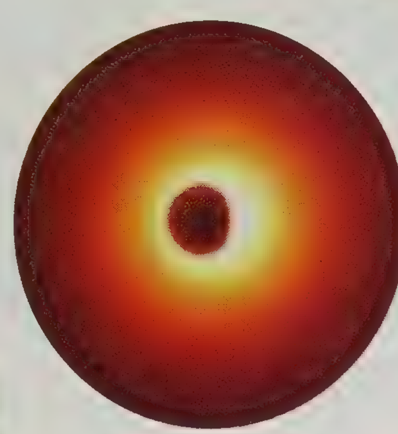
Marsalis came a participant in 1990. TIAA-CREF Individual and Institutional Services, Inc., and Teachers Personal Investors Services, Inc., distribute securities products.
Insurance and Annuity Association–College Retirement Equities Fund (TIAA-CREF), New York, NY. Ellis Marsalis was compensated.

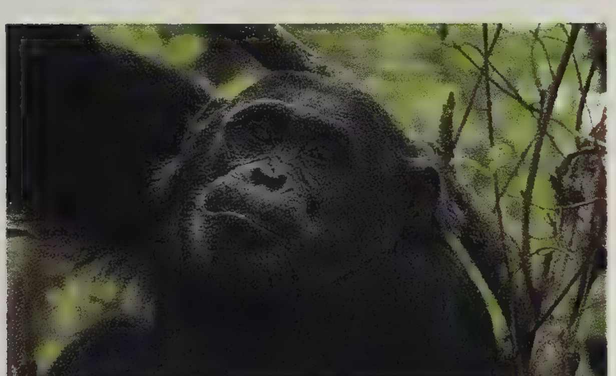
NATURAL HISTORY

JUNE 2003 VOLUME 112 NUMBER 5

FEATURES







COVER
Ron van Dongen, *Cryptanthus zonatus*, 1999

STORY BEGINS ON PAGE 34

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DEPARTMENTS

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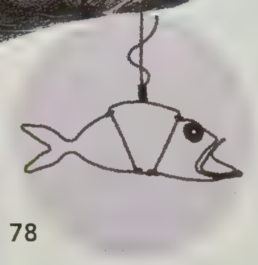

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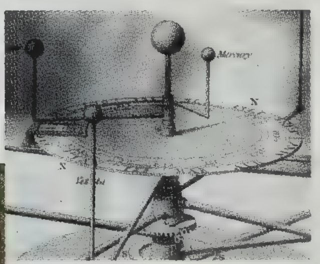

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6

PICTURE CREDITS: Page 10

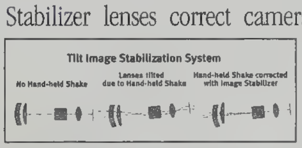
Some people see a brilliant star reasserting his dominance.

We see 32 of our lenses dominating a tennis match.

Those distinctive white lenses. Canon's unrivaled collection of over 50 EF lenses are everywhere serious photographers work. Especially our trademark white ones. That's because, quite simply, they're the world's most advanced lenses for the world's most advanced cameras, analog or digital.

Advanced Optics. Canon pioneered Aspherical Lens technology for SLRs, to correct conventional spherical lens distortion. The result is high contrast and resolution with minimal flare, even with large-aperture lenses. We also tackled the problem of chromatic diffraction. To that end, we created lenses of crystalline fluorite and super UD glass, which required entirely new production technologies. In addition, Canon created unique Diffractive Optics lenses, like the EF 400mm f/4 DO IS USM. These lenses boast higher image quality, even with reduced size and weight.

Image Stabilization. Canon's exclusive Image Stabilizer lenses correct camera shake signifigantly.



In fact, they increase usable shutter speed range by up to a remarkable 3 full steps for hand-held shooting.

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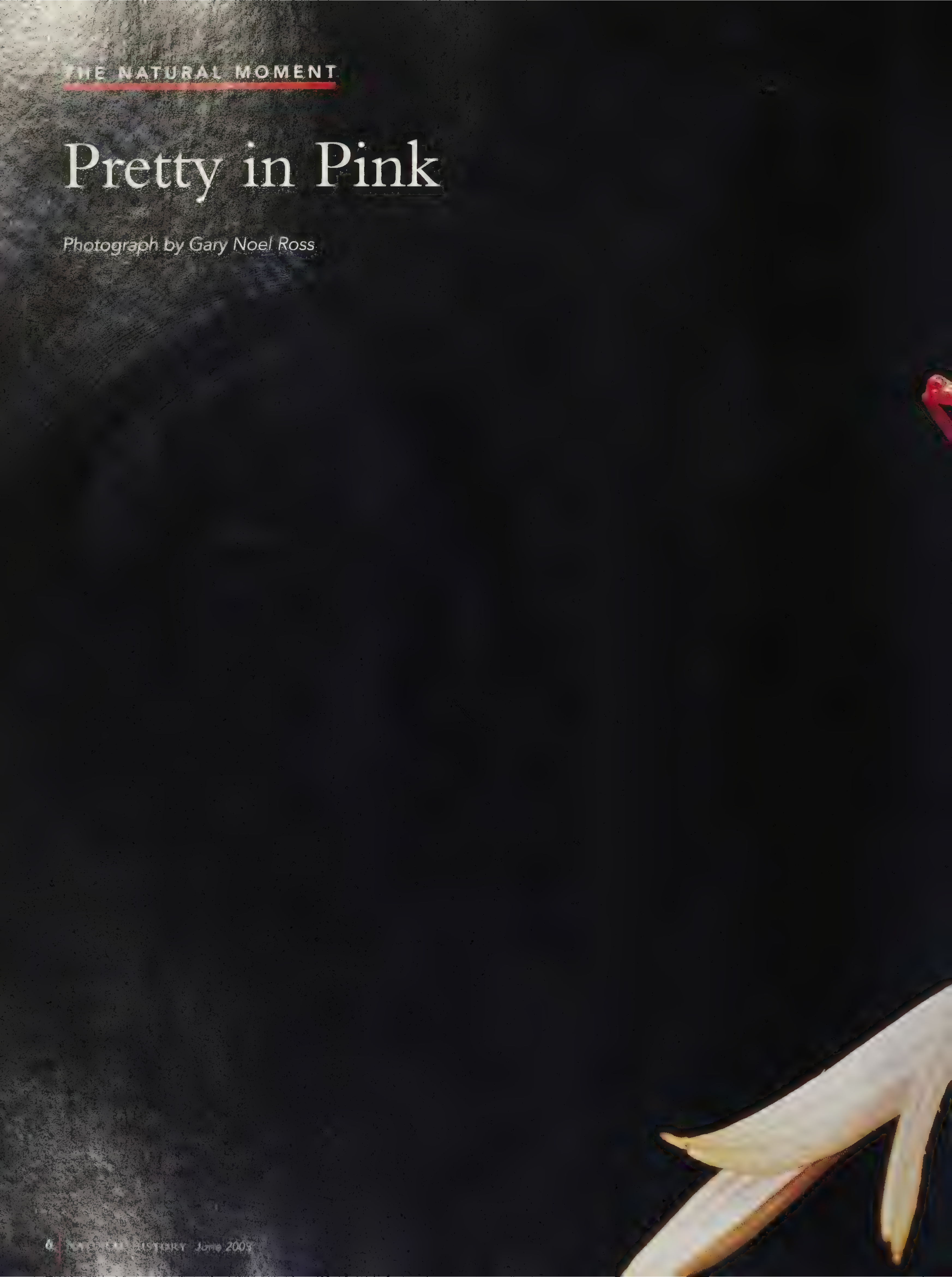
THE NATURAL MOMENT

Pretty in Pink

Photograph by Gary Noel Ross



THE NATURAL MOMENT

◄ *See preceding pages*

Like most other katydid species, the western round-winged katydid *(Amblycorypha parvipennis)* is normally green. But throughout its range, from South Dakota to central Texas, both pink and yellow variants occasionally pop up. My pink lady—for this was a female—was still a wingless juvenile when I came across her one early June morning in western Missouri's Wah' Kon-Tah Prairie. To get better acquainted with this rarity, I placed her in a terrarium.

Then I began to worry—the insect wouldn't feed on the greens I offered her, all prairie grasses and leaves that should have appealed to a katydid. But then, observing that her color was well matched by the pale purple coneflower, I offered her a bloom. She immediately began to nibble on the petals.

After a few days I tried an experiment to see if she got her pink pigment from the flowers: I started her on a diet of yellow blooms. But even though she feasted on yellow for the rest of her two-month confinement, I found no hint of jaundice. Apparently the color was in her nature, not her nurture. Ongoing research on related species, by David A. Nickle, an entomologist with the USDA's Agricultural Research Service, and others, is untangling how katydid color variation is genetically determined.

Why a pink (or yellow) katydid? My guess is that the variants, adapted to feeding on diverse kinds of flowers, help a katydid species enlarge its niche. The color camouflage is simply a tool the insects need to survive.

—*Gary Noel Ross*

UP FRONT

Front-Page News

For more than a decade I've been pointing out to anyone who would listen that science and nature are big news. Disease organisms are news—think of AIDS, or anthrax, or SARS. Space exploration is news. The crisis in biodiversity is news. Environmental degradation, earthquake prediction, energy resources, the Iceman, and genetically modified crops are all news. You can't be current on the events of the day without being on top of what's happening in science.

Seldom have we at *Natural History* more keenly felt this observation than we have this month. In Baghdad looters rushed into the National Museum, plundering priceless archaeological artifacts. We decided to cover the disaster primarily by showing some of the artifacts—and leaving the reader to contemplate the fact that some of them may never be seen again. We also invited David Keys, a freelance reporter who specializes in archaeology, to pull together the main threads of the story so far. Finally, John Malcolm Russell, an expert in Near East archaeology who wrote "Robbing the Archaeological Cradle" for the February 2001 issue of *Natural History,* has graciously allowed us to reprint excerpts from his still all-too-relevant article. All three elements are collected under the title "Lost Time" (page 42).

As we go to press, another breaking news story has touched us closely. We have learned to our dismay that Subhankar Banerjee, the photographer of "Arctic Covenant" in our April 2003 issue, has become caught in the continuing political cross fire over oil drilling in the Arctic National Wildlife Refuge (ANWR). Banerjee's photographs documented the wildlife and flora of the refuge against the stunning backdrop of mountains and floodplain.

On March 19 Senator Barbara Boxer, a California Democrat, held up Banerjee's book—from which our portfolio was excerpted—on the floor of the U.S. Senate. Advocates of drilling, particularly Senator Ted Stevens, a Republican from Alaska, had portrayed the region as a barren land, devoid of wildlife for all but a few months a year. Boxer challenged that view, citing the book.

The reaction was virtually immediate. According to *The New York Times,* Banerjee's photographs, which were scheduled for display in the main-level rotunda at the Smithsonian Institution's National Museum of Natural History in Washington, D.C., were moved to a far less prominent gallery there. Captions for the photographs were shortened from discursive to telegraphic. A letter from Lawrence M. Small, the head of the Smithsonian, responding to a request for an explanation by Illinois Democratic Senator Richard J. Durbin, maintained that the earlier captions "might have been construed as advocacy" for ANWR, and were therefore excluded as a matter of Smithsonian policy.

The entire episode reflects the personalizing and retributive nature of contemporary political discourse. According to the *Times,* Stevens had told his Senate colleagues: "People who vote against [the drilling] are voting against me. I will not forget it." Stevens serves on the Senate oversight subcommittee for the Smithsonian, as does Durbin, and so the Smithsonian can hardly be blamed for fretting about its political support. Stevens's office denies putting any pressure on the museum. But self-censorship—if that's what it is—is still a slap in the face of free expression, and a repugnant consequence of the struggle to survive in a climate of intimidation.

—PETER BROWN

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CONTRIBUTORS

GARY NOEL ROSS ("The Natural Moment," page 6) was cataloging the butterflies in Missouri's Wah' Kon-Tah Prairie when he flushed out a katydid whose color seemed as outlandish as the Pink Panther's. Although based in Baton Rouge, Louisiana, Ross was then serving as "lepidopterist in residence" at the 7.5-square-mile prairie. Formerly a professor of biology at Southern University in Baton Rouge, Ross is director of butterfly festivals for the North American Butterfly Association.

To learn more about the complexity of nature, **SCOTT CAMAZINE** ("Patterns in Nature," page 34) became a biologist, a physician, and a photographer. His recent research has largely been devoted to the study of honey bee societies. Camazine was fascinated by the natural world as a child, and eventually became obsessed with the question of how complex patterns emerge and are maintained in nature, the subject of his article in this month's issue. (See his home page at http://www.scottcamazine.com/.) He is a co-author of *Self-Organization in Biological Systems,* published in 2001 by Princeton University Press.

Having spent several years observing the hunting behavior of chimpanzees in Gombe National Park, Tanzania, **CRAIG STANFORD** ("Close Encounters," page 46) decided to study the relations between chimpanzees and gorillas in Uganda's Bwindi Impenetrable National Park. Initiated in 1996, his Bwindi Impenetrable Great Ape Project (www-rcf.usc.edu/~stanford/bigape.html) examines how much the two species overlap in their use of the habitat's resources as well as the implications of that overlap for conservation initiatives and for the interpretation of ancient hominid adaptation. Stanford is a professor of anthropology and biological sciences at the University of Southern California in Los Angeles, and co-director of the university's Jane Goodall Research Center. His book on early human evolution, *Upright: The Evolutionary Key to Becoming Human,* is slated for publication by Houghton Mifflin later this year.

Astronomer **FULVIO MELIA** ("Peering at the Edge of Time," page 52), an Australian expatriate living in Arizona, wants to put Einstein's general theory of relativity to the ultimate test—by exposing it to the intense gravity of our galaxy's central, supermassive black hole. A professor of astronomy at the University of Arizona in Tucson, and an associate editor of *Astrophysical Journal Letters,* Melia also brings his love for the beauty of the night sky to his writing for a general audience. When he's not looking up, he enjoys history, fast cars, and Australian Rules football. His article in this issue is adapted from his book *The Black Hole at the Center of Our Galaxy,* which is being published by Princeton University Press.

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A Long Jump

The first literary mention of the ancient Greek athletic event known as the long jump, whose biomechanics are discussed in Adam Summers's column "Throwing Yourself into It" [4/03], is in book VIII of the *Odyssey.* Homer presents it as an after-dinner contest performed for Odysseus, but makes no mention of the use of *halteres,* or weights, by the jumpers.

Mr. Summers asserts that the competitive long jump was a standing event; on the contrary, it seems to have been a running jump. That interpretation arises in part from the fact that ancient Greek has words for the jumper's takeoff board *(bater)* and his earthen landing pit *(skamma),* neither of which should have been necessary for a standing jump. Halteres may have been used at times for the standing long jump, but probably not for the competitive event. Several literary sources recount long jumps exceeding fifty feet.

The first Olympic victor in the long jump was Lampis of Sparta, who in 708 B.C. won the pentathlon—a contest consisting of five separate events, including the long jump. The earliest vase paintings that depict jumping with weights date from the sixth century, and the oldest surviving weights from about 600 B.C. So one might ask whether and how Lampis and other early long jumpers actually used weights. Philostratos, a third-century A.D. sophist, tells us that halteres—a "sure guide for the hands and for bringing the feet cleanly to the ground"—were invented by the pentathletes themselves; judging by his comment that halteres were good for the shoulders and hands, athletes probably would have used them as dumbbells are used today—as training weights.

David Gilman Romano
University of Pennsylvania
Philadelphia, Pennsylvania

"So, what do ornithologists do to relax?"

ADAM SUMMERS REPLIES: Both standing and running long jumps may have been ancient Olympic events. The jump shown on many vases certainly appears to be a standing long jump, because the arms are moving together. In a running long jump the arms are out of phase, one behind and the other in front. It's difficult to envision a biomechanical benefit for halteres in that kind of jump.

In reference to the fifty-plus-foot jumps, some scholars believe those figures result from combining the outcomes of several standing long jumps.

Biologists have adopted the term "halteres" to refer to the rear vestigial "wings," or balancers, in dipterans (two-winged flies, mosquitoes, gnats, and so on). Curiously, in the fruit fly, a single gene mutation is capable of making the halteres revert to a second set of wings, thus anatomically removing the mutated flies from the order Diptera.

Frank Sturtevant
Sarasota, Florida

Entomophilia

I enjoyed Le Anh Tu Packard's article about the giant water bug known in Vietnam as the *ca cuong* ["Bug Juice," 3/03]. The insect is a food delicacy not only in Vietnam but also throughout Southeast Asia. In Thailand—where, according to the English entomologist William S. Bristowe, writing in 1932, "it reaches the tables of princes in Bangkok"—it is known as *malaeng da na.* Although artificial bug flavoring is now available, the Thais still prefer the real thing.

More information about this delectable insect is available in chapters 24 and 25 of my online book "The Human Use of Insects as a Food Resource" (www.food-insects.com).

Gene R. DeFoliart
University of Wisconsin–Madison
Madison, Wisconsin

Surf and Turf

I read with great interest Robert S. Semeniuk's article "How Bears Feed Salmon to the Forest" [4/03], on the work of Thomas E. Reimchen in investigating marine-derived nutrients in forest ecosystems. Fisheries biologists have long regarded Pacific salmon as "keystone species" because of their ability to transport vast amounts of oceanic nutrients far inland during spawning migrations. Reimchen's research adds complexity to the existing paradigm by delineating the second stage of the "nutrient pump": large carnivores transporting huge numbers of salmon carcasses into the terrestrial environment. Marine-derived nutrients thus get distributed over a far greater area than they would be otherwise. Hence bears, being an integral part

of the nutrient pump, are critical to the health of the Pacific Northwest's coastal ecosystems.
Kenneth I. Ashley
University of British Columbia
Vancouver, British Columbia

Democracy in Space

Neil deGrasse Tyson's cogent essay "Reaching for the Stars" [4/03] correctly identifies what might be called the "categorical imperatives" that have universally governed human forays into the immense and the unknown: defense, commerce, and spiritual or temporal power. But he doesn't explicitly mention a pertinent feature of the history of grandiose projects, a feature common to Chinese emperors, Iberian royalty, and Egyptian pharaohs responsible for the wonders of past ages: they were all autocrats who did not require the permission of their governed to launch their initiatives.

Today, however, proponents of space exploration must persuade not just one monarch (and perhaps a few influential advisors) to implement a stupendous dream. The United States is a democracy, in which an entire population, or at least their hundreds of elected representatives, must be persuaded. Advocates of space exploration must show that it is directly pertinent in the near term not merely to the parochial interests of a select sliver of the populace, but also to the pragmatic concerns of the vast majority.
Robert E. Becker
Grand Rapids, Michigan

Picture Imperfect

On page 58 of the article "Vietnam's Secret Life," by Eleanor J. Sterling, Martha M. Hurley, and Raoul H. Bain [3/03], is a photograph of a single branch of the golden Vietnamese cypress, showing both needles and scales. The caption says that it is highly unusual for a mature tree to "bear both needles and scales." Yet nearly all mature redwoods *(Sequoia sempervirens)* have needles on their low foliage and scales on their upper foliage, reflecting the humidity gradients found in tall forests.
Roman Dial
Alaska Pacific University
Anchorage, Alaska

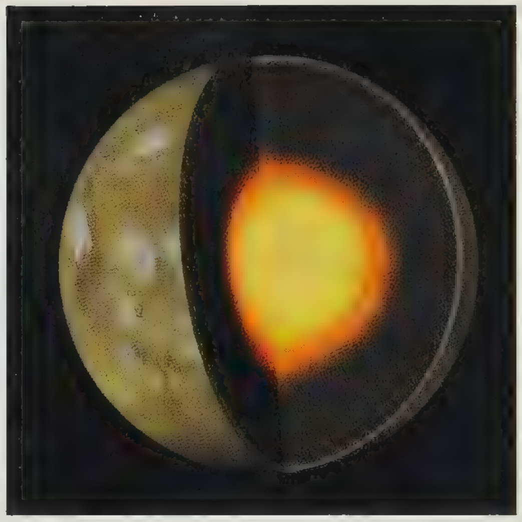
MARTHA HURLEY REPLIES: The caption should have specified that for a mature tree to bear both needles and scales *on the same branch* is highly unusual; in fact, this trait characterizes all cypresses, and is one way to identify them.

Redwoods do bear both kinds of foliage simultaneously on the same tree, though not on the same branch; in addition, a number of related species undergo a transition between the two foliage forms as the plants mature.

Natural History*'s e-mail address is nhmag@amnh.org.*

By Stéphan Reebs

UN-SOLID GROUND Most people probably don't give much thought to the two faint, ever-shifting double bulges that are continuously sliding across the surface of our planet. Those bulges are called solid-body tides; the larger of the two is caused by the Moon (the other by the Sun), and it's pretty subtle: about one foot high at its maximum. But if the Earth had a solid core instead of one whose outer 94 percent is liquid, the bulges would be some 30 to 40 percent smaller. The effect is the result of two phenomena: the gravitational pull of the Moon or the Sun, coupled with the relative elasticity of a planet with a partly liquid core.



Inside Mars

Now Charles F. Yoder, a planetary scientist at the Jet Propulsion Laboratory in Pasadena, California, and his colleagues have measured solid-body tides elsewhere in the solar system. Not only have they done it with remarkable precision, but, intriguingly, they've also determined that the solid-body tides on Mars—caused by the Sun, not by a Martian satellite—are large enough to indicate that at least part of that planet's core is liquid.

Until recently, planetary geologists had no direct evidence that Mars had a solid core. But after Yoder's team analyzed three years' worth of radio signals from NASA's *Mars Global Surveyor* and tracked the spacecraft's orbit around Mars, their data showed a slight but continuous change in the tilt of *Surveyor*'s orbit: a shift of about 0.001 degree a month. Early in the study, the investigators realized only a liquid core could give rise to a tidal bulge capable of having the observed gravitational effect on the spacecraft. And how much bulge is that? About a third of an inch. ("Fluid core size of Mars from detection of the solar tide," *Science* **300:**299–303, April 11, 2003)

COLD PASSAGE Several Novembers ago, off the coast of Greenland, the captain of a fishing vessel was puzzled by one of the fish caught in the boat's gill nets. He decided to put it on ice and ask experts to identify it. Peter Rask Møller, a zoologist at the University of Copenhagen, and his colleagues have now pronounced the six-foot-long, 155-pound beast to be a Patagonian toothfish, *Dissostichus eleginoides*.

The surprising word here is "Patagonian." *D. eleginoides*, an overfished species marketed in the United States as "Chilean sea bass," had never before been sighted in the Atlantic Ocean north of Uruguay. To reach Greenland, the hardy traveler had to swim at least 6,000 miles at depths of at least 1,600 feet; closer to the surface, temperatures in the tropics would have been lethal to such a cold-water specialist.

The only other explanation for the finding would be the previously unrecognized existence of a resident northern population. But that seems unlikely: two decades of intensive deep-sea fishing in the North Atlantic have turned up only that lone toothfish. Yet some marine creatures do exist in separate northern and southern populations. The wandering toothfish suggests deepwater migration might have led to those discontinuous distributions. ("Fish migration: Patagonian toothfish found off Greenland," *Nature* **421:**599, February 6, 2003)

HOME, SWEET HOME On Earth, where there's water, there's usually life. But few people would expect to find life in an isolated reservoir of 4,300-year-old seawater locked inside the basalt crust that forms the bottom of the world's oceans. The water is hot—a sweltering 149 degrees Fahrenheit—and almost entirely isolated by hundreds of feet of impermeable sediment (the exceptions to total isolation may be a few scattered, rocky seamounts that pierce the sediment blanket). But a team of scientists led by James P. Cowen of the University of Hawaii in Honolulu decided to check it out for life anyway.

First they had to obtain water from the crustal reservoir without contaminating it—quite a feat in itself. In the mid-1990s the international research partnership known as the Ocean Drilling Program bored a hole in the Juan de Fuca Ridge, in the northeastern Pacific. The drilling, in 8,530 feet of water, went down through 810 feet of sediment and then an additional 157 feet of seamount crust. Pressures at the bottom of the ocean are enormous, but they're even greater within the crust's high points, and so crustal water gets pushed all the way up to the seafloor at the top of the drill-hole. Cowen and his team took advantage of a clever collection device, recently installed, that captures the fluid before bringing it to the surface. Samples can thus be examined for any micro-denizens of the deep that might reside there.

What did the team find? In the water were swarms of bacteria and archaea (ancient microorganisms that often thrive in tough places), as many as a few million per ounce—perhaps not as crowded as pond scum, but similar to the density near the seafloor. Some of the microorganisms are genetically similar to the heat-loving bacteria that live in the sulfurous hot springs of Yellowstone National Park. And some of the critters get their energy from nitrates, rendering the water around them rich with ammonia. However uninviting to most of Earth's inhabitants, the reservoir is further proof that even in what most life-forms would regard as noxious quarters, an empty niche is hard to find. ("Fluids from aging ocean crust that support microbial life," *Science* **299:**120–23, January 3, 2003)

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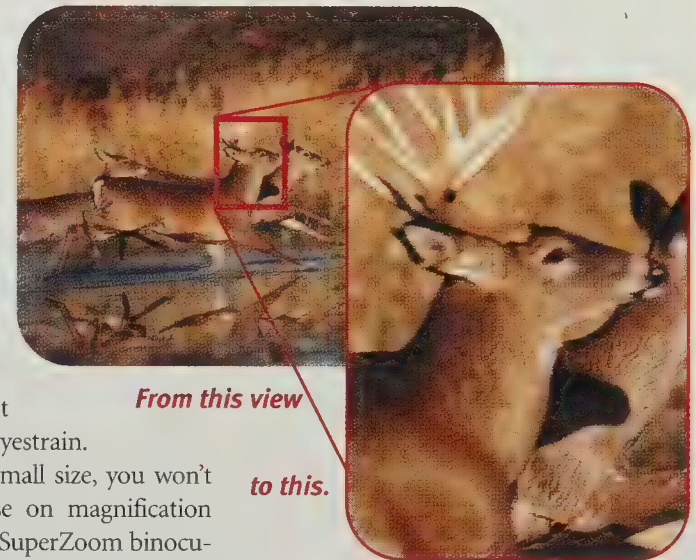

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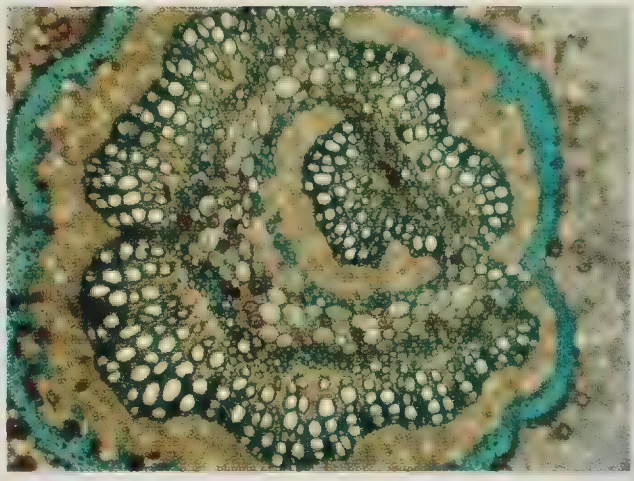
IN THE SAME VEIN The network of blood vessels in a human being is not only extensive, it's also finely engineered. Some anatomists say that, placed end to end, the vessels would stretch 60,000 miles. As for the engineering, the British biologist Cecil D. Murray calculated the optimum size and number of each kind of conduit in 1926—assuming that nature would invest as little as possible in construction materials without jeopardizing the smooth flow of blood. Subsequent research showed that Murray's simplifying assumptions predicted the patterns of animal circulatory systems fairly well. In a precise, quantifiable way, the conduits increase in both number and total cross-sectional area as they get farther from the source of the fluid they carry.

Until recently, though, "Murray's law" had never been seriously tested in plants. One reason may be that many conduits in plants not only transport water but also support the plant, undercutting the rationale for trying to apply the law. A team of biologists at the University of Utah in Salt Lake City, however, noted that some vascular conduits in plants provide little structural support. So they anticipated that the vessels in vines and in compound leaves such as those of the box elder—as well as in "ring-porous" trees such as ash, which make one ring of nonsupporting conduits every year to transport water from roots to leaves—might well conform with Murray's law.



Cross section of a box elder leaf's petiole

One of the biologists, Katherine A. McCulloh, spent two years slicing thin cross sections of leaves, stems, and branches from local trees and vines; photographing the thin sections under the microscope; and measuring the diameters of nearly 100,000 of the plants' water-bearing conduits with the help of image-analysis software. Her results bore out Murray's law: like us, plants have optimally efficient plumbing systems. Blood may be thicker than water, but the pipes that carry both of them follow the same rules of design. ("Water transport in plants obeys Murray's law," *Nature* **421**:939–42, February 27, 2003)

EXPERIMENT OF THE MONTH Use it or lose it: that's a rule that governs employee vacation days—and bones. In every bone there's a steady turnover of material, a continuous balancing act between bone formation and the resorption of bone tissue into the bloodstream. Those two processes are kept in healthy equilibrium by the near-constant compression and tension exerted on working bones. But if bones are not put to work, tissue formation slows down and resorption speeds up, and the bone structure weakens. Bedridden patients—and weightless astronauts in space—are prone to fractures simply because their bones aren't being used.

Black bear hibernating with her cub

But that raises a question: What about hibernating bears? Are their bones compromised by five to seven months' rest? To find out, Seth W. Donahue, a biomedical engineer at Michigan Technological University in Houghton, along with several colleagues, analyzed blood from seventeen wild black bears. (Blood samples are easier to get and less invasive than bone samples, and levels of certain protein fragments in the blood reflect the rates of bone formation as well as resorption.) First, however, Michael R. Vaughan of Virginia Tech in Blacksburg had to fit the bears with radio collars so that the investigators could locate the animals in summer and in winter, dart them with an anesthetic (even during hibernation bears can move with reasonable alacrity), and collect a few drops of blood.

The blood samples, as expected, showed substantial bone resorption, but surprisingly, bone formation had not slowed. Furthermore, the investigators detected a spurt of bone formation in early summer—greater than the bone growth measured in any other healthy adult mammal—that canceled out the net bone loss caused by a winter of inactivity. The result offers some long-term hope for people who suffer from osteoporosis or other bone diseases: bears could serve as a useful animal model in the search for effective treatments. ("Serum markers of bone metabolism show bone loss in hibernating bears," *Clinical Orthopaedics and Related Research* **408**:295–301, March 2003)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

The Rise and Fall of Planet X

Neptune and Pluto were supposed to "fix" the weird orbit of Uranus. Now, it seems, the orbit wasn't "broke."

By Neil deGrasse Tyson

Heard about Planet X lately? Probably not. It's dead—no matter what anybody has told you. Astrophysicists no longer need to postulate the existence of an "undiscovered" planet to explain the motions of the other planets in our solar system.

The rise of Planet X begins with the German-born English astronomer Sir William Herschel, who more or less accidentally discovered the planet Uranus on March 13, 1781. That episode was an exciting moment in eighteenth-century astronomy. Nobody in recorded history had ever discovered a planet. Mercury, Venus, Mars, Jupiter, and Saturn can each be seen relatively easily with the naked eye, and all were known to the ancients. So strong was the bias against finding additional planets that Herschel, even in the face of contrary evidence, assumed he had discovered a comet. Other eighteenth-century star watchers were in denial as well. Charles Messier, the French astronomer and consummate comet hunter, noted, "I am constantly astonished at this comet, which has none of the distinctive characters of comets."

Archival records of star positions show that several observers had seen Uranus before Herschel did, but each one had mistakenly classified the planet as a star. In an embarrassing example from January of 1769, the French astronomer Pierre Charles Lemonnier did not discover Uranus six times! When Herschel finally noted that the mysterious object moved, astronomers were able to calculate an orbit with good precision because of the availability of nearly a century's worth of "prediscovery" data on its position in the sky. Their calculations showed that the object's orderly, near-circular path, far from the Sun, had nothing in common with the eccentric trajectories of all known comets. At that point, you would have had to be both blind and boneheaded to resist calling the new object a planet.

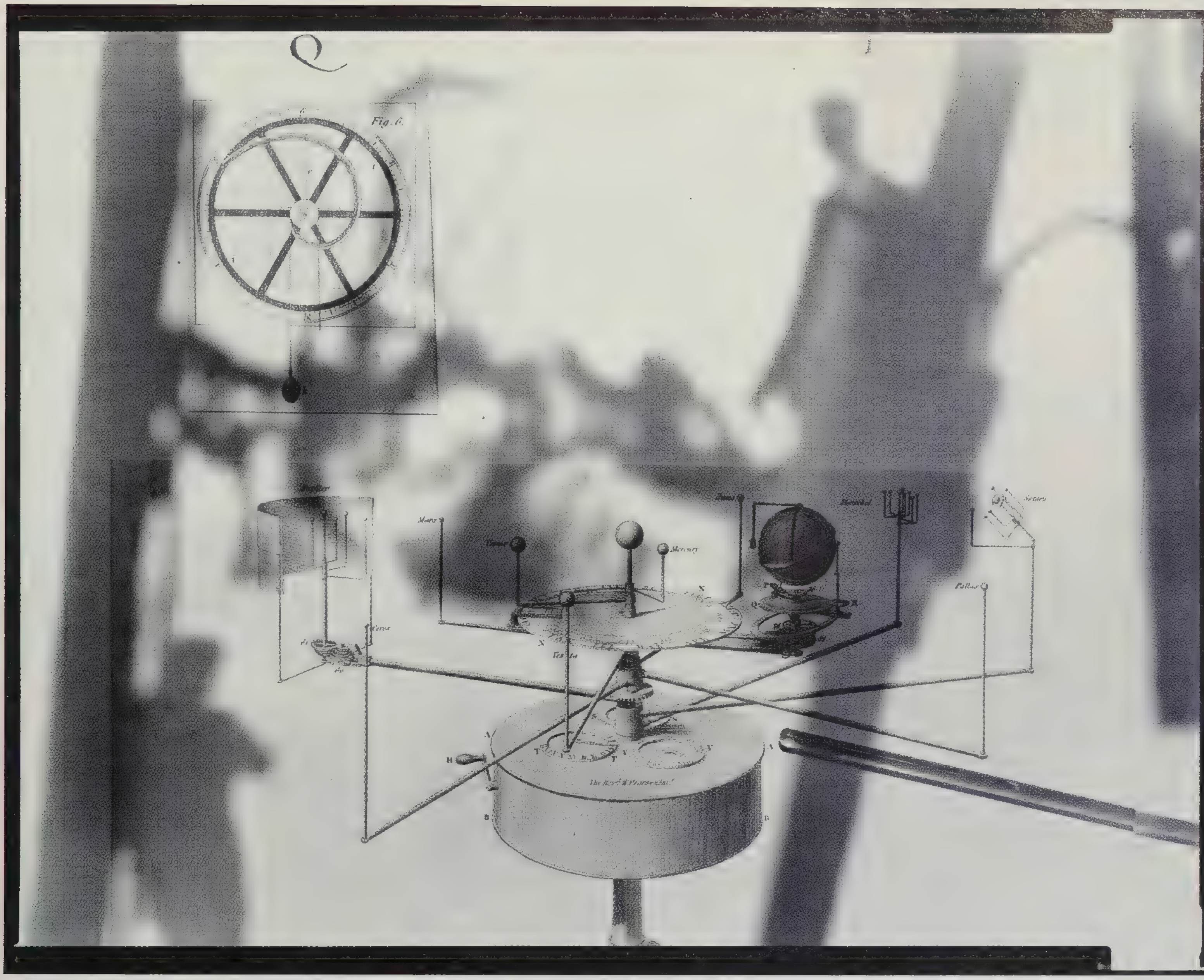
Uranus was behaving so badly that it seemed to ignore even Newton's law of gravity.

But all was not orderly in the solar system. Uranus was behaving badly. The new planet was not moving through space the way astronomers expected it to. Its trajectory around the Sun was not following the path Newton's law of gravity would have it take. The historical observations fitted one orbit; the post-1780s telescopic observations fitted another.

Some astronomers suggested that Newton's laws might be invalid at such large distances from the Sun. That wasn't as crazy as it sounds—under new or extreme conditions the behavior of matter can and does deviate from the predictions of the known laws of physics. But only if Newton's theory of gravity had been nascent and untested would there have been good reason to doubt it. By the time Herschel discovered Uranus, however, Newton's laws had had a hundred-year run of successful predictions. The most famous of them was Edmond Halley's prediction of the 1758 return of the comet that would be named in his honor.

The simplest conclusion? Something else had to be out there, something yet undiscovered, whose gravity had not been accounted for in the predicted orbital path of Uranus.

In the life cycle of a physical theory, a scientist first makes a testable prediction about the world. Then a skeptical colleague runs a few actual experiments to see how well the prediction stands up to reality. The arithmetic differences between the theory's predictions and the experimenter's data are sensibly called "residual errors"—"residuals" for short—and they're the measure of a theory's success. Small residuals are good; big residuals are bad. If the theory describes nature accurately, and the experiment is well designed,



Olivia Parker, *Weighing the Planets*, 1984

the residuals are not only small, but they fluctuate between positive and negative values from one measurement to the next, yielding an average close to zero. If the average is anything other than zero, one can rightly say that crucial differences exist between the predictions and the measurements.

When that happens, it's not easy to assign blame. Maybe the theory needs to be modified, or maybe somebody blundered when the measurements were taken, or both. If your theory of gravity predicted that an object should fall upward when released, the theory would require significant modification, because the residuals between the predicted positions and the actual positions along the object's trajectory would be gigantic, and would not average to zero.

In the late eighteenth century the French mathematician Pierre-Simon de Laplace invented perturbation theory [*see "Going Ballistic," by Neil deGrasse Tyson, November 2002*], giving astronomers an indispensable tool for analyzing the small gravitational effects of an otherwise undetected celestial object. Encouraged by the expansion of their arsenal, mathematicians and astronomers across Europe continued to investigate what might be perturbing Uranus. In 1845 a young, unknown English mathematician, John Couch Adams, approached Sir George Airy, Britain's astronomer royal, with a request that he search a specific patch of sky for an eighth planet. But neither looking for planets nor following the leads of spunky young mathematicians was part of the astronomer royal's job description, so Adams's request was dismissed. The next year, the French astronomer Urbain-Jean-Joseph Le Verrier independently derived a similar prediction. On September 23, 1846, he communicated his prediction to Johann Gottfried Galle, who was then assistant director of the Berlin Observatory. Searching the sky that very night, Galle found the new planet, soon to be named Neptune, within a single degree of the spot Le

Verrier had predicted. It took him only an hour to locate it.

But once again, all was not orderly in the solar system. Uranus was still behaving badly. Its orbital residuals got smaller, but they didn't go away, even with the gravity of Neptune accounted for. And Neptune's orbit had some residuals of its own. Could yet another planet be waiting to be discovered?

In 1894 Percival Lowell, an independently wealthy American astronomer, built the eponymous Lowell Observatory in Flagstaff, Arizona. Lowell indulged a fanatical fascination with Mars, claiming that intelligent civilizations were in residence there, but he devoted most of the rest of his life to the search for the object he called Planet X ("X" for the algebraic unknown)—the mysterious body in the outer solar system that continued to perturb Uranus and Neptune.

One way to look for a planet is to make two photographs of the same patch of sky through a telescope, several days (or years) apart. But the next step is the rub: nobody wants to pore over images of the sky made up of countless millions of dots, hoping to spot the one that moved between one photo and the next. Fortunately, an ingenious mechanical-optical device known as a "blink comparator" would come to the rescue. This contraption, an early-twentieth-century innovation, exploits the remarkable ability of the eye to detect change or motion amid an otherwise unchanging field. First you place the two photographic images side by side in precise alignment. Next, you flash the two images back and forth in rapid succession. Against the background star field, any speck on the two photographs that brightens, dims, or shifts position from one photograph to the other becomes immediately apparent. In the search for Planet X, the blink comparator minimized many sources of human error, including spurious measurements made by sleepy astronomers in the middle of the night.

At about four in the afternoon on February 18, 1930, a twenty-four-year-old amateur astronomer named Clyde W. Tombaugh discovered Planet X. He had been hired the year before by the Lowell Observatory to continue the arduous search. (Lowell himself had died in 1916.) The young fellow was looking at a pair of photographic plates he had taken on January 23 and 29 of the region around the star Delta Geminorum. Tombaugh became the third and last person ever to discover a planet in our very own solar system. On March 13 the observatory announced the news.

You don't stop your survey just because you've discovered something.

In Tombaugh's day many people associated the name given to the ninth planet with Pluto Water, a widely used laxative bottled on the grounds of the palatial French Lick Springs Hotel in Indiana, about fifty miles south of Bloomington. Other suggestions for names included Artemis, Atlas, Bacchus, Constance, Lowell, Minerva, Zeus, and Zymal. But "Pluto" eventually triumphed because Pluto is, after all, the god of the underworld, the realm of darkness—and what else, if not darkness, prevails four billion miles from the Sun? And because Jupiter and Neptune are Pluto's mythological brothers, the name also maintains a happy family. Finally (and perhaps fortuitously), the first two letters of "Pluto" are the initials of Percival Lowell, who instigated the search in the first place. [*See "Pluto's Honor," by Neil deGrasse Tyson, February 1999.*]

In any well-designed, well-conducted survey, you don't stop just because you've discovered something. By completing the survey, you might discover much more. So for the next thirteen years Tombaugh searched more than 30,000 square degrees of sky (out of a total of 41,253 square degrees). He found no more planets with a brightness equal to or greater than that of little Pluto. But his time wasn't wasted. The survey revealed hundreds of asteroids, six new star clusters, and a comet.

But was Pluto the Planet X of everybody's suspicions? Nope. Over the decades, as the measurements of Pluto's mass became more and more accurate, astronomers learned how little the place really is. Turned out it's far too small to account for the residuals of Uranus and Neptune. So Planet X still had to be lurking, undiscovered, in the outer limits of the solar system.

That, at least, was the prevailing belief until May 1993, when E. Myles Standish Jr. of the Jet Propulsion Laboratory in Pasadena, California, published a paper in the *Astronomical Journal* titled "Planet X: No Dynamical Evidence in the Optical Observations." Standish used the updated mass estimates of Jupiter, Saturn, Uranus, and Neptune that had become available from the Voyager flybys; in the case of Neptune, the mass difference amounted to nearly 0.5 percent—quite large by today's standards.

Assuming that the masses derived from the Voyager missions were accurate (a wise move), and discounting a single set of suspicious measurements made at the U.S. Naval Observatory between 1895 and 1905 (another wise move), Standish recalculated all the orbital parameters. The result? The large systematic trends in the residuals of Uranus and Neptune disappeared, and the remaining small residuals were consistent with the observational uncertainties of the modern data. In plain English: the apparent anomalies in the orbits of Uranus and Neptune could be completely explained within the framework of the presently known solar system. In even plainer English: Planet X was dead. But was it buried?

Several years ago, shortly after Clyde Tombaugh died at the age of ninety, Pluto's planethood was thrown into question. Seven moons in the solar system are bigger. More than half its volume is ice, as is the case for comets. For a twenty-year stretch of Pluto's 248-year journey around the Sun, its elongated orbit takes it closer to the Sun than Neptune gets. And Pluto's moon, Charon, is massive enough to cause the center of gravity of the Pluto-Charon system to lie outside Pluto itself. Each of these distinctions has no counterpart among the other planets. Yet the Rose Center for Earth and Space in New York City got into big trouble with the national press and with third graders for being the first major public institution to demote Pluto in its exhibits on the solar system. Not only was Pluto not Planet X: now poor Pluto wasn't even a planet.

In a further insult to Pluto's ego, Caltech astrophysicists recently discovered Quaoar, an icy world in the outer solar system that (like Charon) checks in at about half the diameter of Pluto. It's made of the same stuff, but Quaoar orbits in a near-perfect circle, something Pluto can only dream about.

If you are sentimental, and want to preserve Pluto's planetary rank, then in all fairness you must add Quaoar to the club—as well as any other yet-to-be-discovered orb that out-planets Pluto. And no, those objects won't be Planet X either. Like Pluto, they are all too small for their gravity to bother anybody but each other.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

Impostor in the Nest

A beetle disguised as an army ant eludes capture by ants as well as entomologists.

By Robert Dunn

In the center of the image, a beetle (Ecitosius robustus) *moves among its host ants,* Neivamyrmex sumichrasti, *as the assemblage investigates a grasshopper femur.* E. robustus *is one of several beetle species that have been found as guests only among* N. sumichrasti *army ants.*

When most people think about the explorers and adventurers of the past, figures such as Captain James Cook or Sir Edmund Hillary come to mind: heroic individuals who explored the world's greatest oceans or climbed the world's highest mountains. My own heroes were another group of explorers, who set out with more modest conquests in mind. They were the natural historians who headed for the hills to chase a new species of beetle, or snare a new bird, or climb a hollow tree to capture a new snake. As an entomologist working in the tropics, I see these collectors as my sometimes humbling, sometimes fumbling predecessors. When I kneel in the forest and turn over rocks, I feel some of the awe my predecessors must have felt.

Unfortunately, though, the days are now few when I get into the field as a biologist, with no more tangled purpose than to find and observe rare species. Darwin had a ship that carried him to biologically unexplored terrain. My colleagues and I are preoccupied with committee meetings, student cheaters, and asbestos abatement.

So when Carl W. Rettenmeyer, a biologist and an emeritus professor at the University of Connecticut,

bumped into me in the hallway in the fall of 2002 and asked whether I would join him on an expedition to the cloud forests of Costa Rica, I started packing. Our mission: To look for a mysterious army ant and a rarely seen but look-alike beetle that lives in its midst.

The team that left for Costa Rica included Carl and his wife Marian; Charlene and Adam Fuller, photographers, collectors, general natural historians, and veterans of the Rettenmeyer army-ant expeditions; and David Lubertazzi and me, graduate student volunteers and all-around grunts. As our plane veered south from Hartford Airport, we left behind the frozen forests of New England for forests where insects, particularly ants, run the show year-round. For mammal watchers, the tropics can bring disappointment; large vertebrates are as scarce there as anywhere else. But the bugs, oh the bugs! Insects overflow in the tropics, both in number and kind. To an entomologist, the tropical forests are more than rich: they are overwhelming. Turn over a log, and one of the hundred or so small animals that scurry away is likely to be a new species of insect.

Many of the first explorers in the New World wrote home about army ants, as have more contemporary writers, natural historians, and the like. Army ants, particularly the species that raid above ground, are dramatic, abundant, and hard to miss. Some of the early or popular accounts of army ants are accurate, but most of them owe more to fantasizing than to observation. The army ants of myth eat everything in their path—children, tapirs, entire villages. They are monsters, to be sure, but predictable ones, scary and inexorable automatons conjured by our collective imaginations. In Carl Stephenson's short story "Leiningen versus the Ants," a Brazilian official says of army ants: "They're not creatures you can fight—they're an elemental—an 'act of God'! Ten miles long, two miles wide—ants, nothing but ants!"

Real army ants are both more interesting and more complex than those of story or myth. Real army ants don't kill people; most of them don't even forage above ground. A typical army ant species lives in nests underground that are built out of the living bodies of its workers. It migrates en masse from place to place as it feeds on the soft brood of other social insects.

The army ant we were looking for, *Neivamyrmex sumichrasti,* was first documented by the French naturalist François Sumichrast, working at the time in Mexico. Sumichrast wrote of the ant that would later bear his name:

> All the researches that I have made up to this time to discover the *formicarium* [nest] . . . have been fruitless, and I cannot obtain any information from the natives where these insects are common.

He observed and collected *N. sumichrasti* from Mexico, but the species ranges throughout the highlands of Mexico and Central America.

Sumichrast's sketchy text was one of the only published accounts of the ant, until Carl Rettenmeyer and his student Roger D. Akre found the ant again in Monteverde, Costa Rica, in 1963. Rettenmeyer studied the species long enough to become fascinated by the odd tagalong guests that live with it. In the years that followed, he often thought about returning to Costa Rica to study *N. sumichrasti* and its guests more completely. Last winter, almost forty years after that initial encounter, he finally got the chance.

Most ants cohabitate with guests, animals that live in or around the colony and depend on the ants for food, shelter, protection, transport, or some combination thereof. Some guests are welcome, others are not, but most are neutral: just there. Many such interlopers are so well adapted to life in the ant's special world that they can survive nowhere else. A single colony of army ants might host dozens of species of beetles, tens of species of mites, and a variety of silverfish and flies. That diversity and beauty has fueled Rettenmeyer's lifelong passion for army ant guests. One of his favorite guests, and the focal point of our mission, was a beetle that's been collected so far by only one scientific expedition (Rettenmeyer and Akre's 1963 trip to Costa Rica)—a little creature named *Ecitosius robustus,* which, roughly translated, means "the robust army ant beetle."

Mythical army ants are scary monsters, to be sure. Real army ants are both more interesting and more complex.

E. robustus is, by all accounts, a remarkable beetle, though any creature able to coexist with army ants would seem to qualify as remarkable. All ant guests have to avoid being eaten by their hosts. Most groups of beetles that live with army ants have evolved one of two body types that enable them to survive among the ants: a flattened, horseshoe-crab-like shape—the better to hunker down when the ants attack them—or the form of the ants themselves, to more easily avoid detection by the ants' probing antennae. Many guests even smell like their hosts—and because most army ants are virtually blind, odor camouflage can be protection enough.

The robust army ant beetle, however, has gone one step further. Many ant guests have evolved to superficially resemble their hosts, but *E. robustus* is unique in being nearly physically indistinguishable from its host ant. The beetle's waist is drawn in to look like the ant's waist. The beetle's antennae are stubby, like the ant's antennae. The beetle's body is dimpled, like the ant's body. Even under the microscope it is hard to tell the two species apart. Rettenmeyer was keen to find the beetles

again, to take their photographs, to watch their behavior—in short, to understand how and why they came to be such exquisite mimics.

But first we had to find the ants.

A few days after we arrived at the biological station of the Monteverde Cloud Forest Reserve, we found two colonies of a species of army ant and brought a few of the ants back to Rettenmeyer in a flask. He raised the ant flask to his nose, took a sniff, and said, "Well, smells like *burchelli*." Each army ant has a particular smell; some are fruity, some are musky. *Eciton burchelli* smells of a combination of tangerine and body odor—unforgettable, once you've experienced it a few times. *E. burchelli* is famous for raiding homes with swarms meters wide, and literally cleaning house—of roaches, crickets, millipedes, and many other arthropods. Because of its predilection for most insect pests, it is welcomed by many people living in neotropical forests, as the forest version of the exterminator.

A segment of a nest of Eciton burchelli *in a Panamanian rainforest. Unlike most army ants,* E. burchelli *often site their nests above ground. The light dots scattered among the blacker forms are the heads of the ants. Within the bivouac, their guests mill about, climbing from ant to ant. Note the two ants at left, linked by their legs.*

Whenever we encountered foraging columns of *E. burchelli* or of other army ants, we would try to trace the columns back to the colony's nest, a transient structure that the ants form from their own bodies. Extending the military metaphor, entomologists call them bivouacs. Each worker ant grabs the legs of the next one, clinging tightly until an edifice of ants is formed. The queen stands in the middle of the cluster with her attendants. The workers hold their positions for hours or even days, guarding their queen and so protecting the future of their own genes.

> ***If you look carefully, you might see a beetle flip onto an ant's back like a miniature cowboy.***

After finding a colony's bivouac, my companions and I would sit and inspect everything going in or out, filming the ants and searching their columns for guests. As we watched, cockroaches, earwigs, isopods, and other small arthropods ran to escape the advancing waves of ants. Even if they managed to avoid the ants, they were usually caught by something else. Small flies laid their eggs in the bodies of the escaping insects; antbirds grabbed most of the bugs the flies didn't claim. The dry leaves crackled with movement. If someone led you blindfolded through the forest, you would still be able to smell the musk-sweet odor of an *E. burchelli* raid and to hear it unfold in the flutter of birds, the tap of the ants' claws on the leaves, and the hum of thousands of tiny flies.

Army ant colonies have distinct phases of activity. For weeks at a time the colony simply forages outward from a single site. Then, when some internal alarm bell rings, the colony begins moving nightly from site to site. When we were lucky enough or patient enough (or both), we would find colonies in their migratory phases. And what moves is an entire ecosystem, all of whose dark parts periodically disassemble themselves, only to reassemble again farther down the trail. The ants leave first, and then their motley crew of guests. Some of the beetles and most of the mites hitch a ride on or under the ants. If you look carefully, you might see a beetle hoist itself up, grab hold of an ant running past, and flip onto the ant's back like a miniature cowboy. Other guests run on their own, using their antennae to follow the chemical trails laid down by the ants. Fifty or a hundred yards farther on, the worker ants form a new nest, and the colony files into place, rapidly at first and then more slowly as the last guests stumble in.

In 1963, when Rettenmeyer first saw *N. sumichrasti* in Costa Rica, he saw it "behind the cheese factory." Amazingly, the cheese factory is still in the same place. Unfortunately, we didn't know whether the elevation marked the top of the range for this species, the bottom of the range, or somewhere in between. We didn't

even know if *N. sumichrasti* was still extant. After days of unsuccessful searching, we began to fear that the ant had gone extinct. Deforestation in the lowlands of Costa Rica has caused the country's cloud forests to become drier, essentially shifting the climatic zones uphill. Many species at middle elevations have moved higher up, where the forest is still wet. Many high-elevation species have become restricted to progressively smaller bands of suitable habitat at the tops of mountains, or, like the golden toad, have gone extinct. *N. sumichrasti,* as far as we knew, was a high-elevation species.

Then one afternoon Dave Lubertazzi came stumbling into the kitchen, sweating and smiling. He held a flask out to Rettenmeyer and said, "Who does this smell like?" Rettenmeyer sniffed and said simply, "*Sumichrasti.* Go back up that hill." Dave and I grabbed some dinner and then ran back up the trail into the forest, our pockets and backpacks clanging with empty flasks.

Usually you can sit beside the trails of army ants and watch for guests as the line goes by. But the beetles that live with *N. sumichrasti* look so much like *N. sumichrasti* that it is nearly impossible to recognize them in the field. We would have to collect all the "ants" we saw and hope that some of them were beetles. When Dave first saw the ants, he had marked their trail with red-and-white striped strings. Now Dave and I went to work beneath the strings, collecting as many individuals as we could. We slowly filled our empty flasks with ants. Glancing downhill at the research station, visible through the canopy of trees, we imagined Carl and Marian Rettenmeyer inside, smiling.

Unfortunately, every time we took a step we crushed ants or obliterated their chemical trail. After a few hours, the ants disappeared. We had no way of knowing where they had gone. We had not been able to track them well enough to find their nest. We were back where we started—without any sign of an ant colony or a nest—except that we now had a few small flasks of *N. sumichrasti*. We returned to the same site the next day and for days after that, but we never found the ants again.

Meanwhile, at the research station, Carl and Marian were filming and photographing the ants we had collected. For hours they watched and took pictures as the ants ran around a circular aquarium. Carl saw one beetle, so he made more photographs, hoping to catch it on film. Afterward, he pulled the critters out of the aquarium, put them in alcohol, and examined them under a microscope. But the beetle we had collected was not *E. robustus* (not antlike enough). Instead it turned out to be an interesting mimic and a new species at that. We crossed our fingers that the beetle we sought would eventually show up in the vials or in Carl's photographs, and went on with our search.

With only a few days left in our trip, we had collected and filmed a great deal (including a scene in which

Two N. sumichrasti *individuals traverse a stick covered in leafy liverwort. Foragers of this species typically travel single file while searching out such small prey as the brood of other ants.*

a colony of army ants crawled over a resting boa constrictor), but we had found little more than a single foraging trail of *N. sumichrasti*. As Adam and Charlene went to search for new colonies, Dave and I went back up the hill to the spot where he had found the trail, hoping it would lead us to the queen and her bivouac. We crisscrossed the slope, walking up and down, swearing and mumbling at each other. We scanned the ground for anything that moved.

After a few hours I gave up, but Dave kept looking. I sat on a root to eat a jelly and jelly sandwich (a bit of a misunderstanding with the cook). On the ground in front of me, I noticed some small black ants that looked a great deal like *N. sumichrasti*. Looking closer, I saw that they were *N. sumichrasti*. I shouted to Dave. We had found them again! We dug and collected, and then radioed to Carl, whereupon the six of us spent the next hour figuring out what to do. After some excited debate, we decided that Dave and I would watch the colony until it stopped foraging for the night, to make sure that it did not emigrate. In the morning, we would all go up together and examine the colony and its bivouac. It would probably be the first bivouac of *N. sumichrasti* ever seen.

So that night, Dave and I went back up the hill with more jelly and jelly sandwiches and sat in near-darkness, observing the colony. The moon was wonderful. We made up constellations and imagined how many strange ant guests we would find inside the nest when we dug it up. We watched ants going in and out of a hole and imagined the million ants inside, grasping one another, guarding their single, bloated queen. After several hours, the colony stopped moving. The ants had called it a night. We walked back down the hill in the faint moonlight and went to sleep.

In the morning, our team trudged back up the hill with shovels, buckets, bags, and cameras. We found the spot where the colony had been, and stopped. There was nothing there. I poked the dirt. Nothing. I stuck a spade into the mud. Nothing. Adam rolled a log over to look underneath. An earwig scampered, a hummingbird squeaked, but not an ant stirred. Either the colony had gone, or what we had seen had not been the colony. To make sure, we flipped a log over and dug some more. Frantically, we searched the hill.

But we didn't find the ants again. We never saw an *N. sumichrasti* queen, or an *E. robustus* beetle. No *E. robustus* beetles were found in our vials or photographs; other beetles showed up, but none as unique as *E. robustus*. The queen had led her small army away, and we would have to wait for another expedition to see her. As we left the forest for our flight back to Connecticut, *N. sumichrasti* foragers carried their prey down tunnels, back to nests full of creatures no one has ever seen.

Robert Dunn is a graduate student completing the final stages of his doctorate at the University of Connecticut, Storrs. His upcoming postdoctoral project, at the Curtin University of Technology in southwest Australia, will examine various aspects of the relation between ants and the seeds they disperse.

An N. sumichrasti *ant (right) tugs at the leg of its guest beetle* E. robustus. *Note the similarity of the beetle's texture, antennae, legs, head, and general shape to those of the ant. The biology of both the guest and the host species remains poorly understood; no one has ever seen the queen of* N. sumichrasti *or the larvae or eggs of* E. robustus. This photograph and the one on page 22 were taken by Carl Rettenmeyer and Roger Akre in Costa Rica in 1963.

FINDINGS

The Owl That Hunts by Light

After years of observing in the Yukon, the author has shown that the North American hawk owl is a more versatile predator than its better known European cousin.

By Christoph Rohner

Unlike other owls, hawk owls depend more on vision than hearing when they hunt.

My first encounter with a northern hawk owl came early in my career, on a cold day in mid-May. Fresh, wet snow weighed down the tree branches, reminding even optimistic souls that spring in the North can be tardy, almost shy. I had arrived that same day, after a week of travel to reach the remote Kluane–Saint Elias mountains, in Canada's Yukon Territory. It was a magnificent setting for a research project on the ecology of the boreal forest, the vast evergreen woods of the north.

As I was taking in the view of snow-laden trees, massive peaks, and Kluane Lake—the largest lake in the Yukon—I spotted the silhouette of a bird perched high in a bare tree. The northern hawk owl, a rare sight in the wild, pinned its yellow eyes on me and let out a sibilant screech that nearly made the hair stand up on the back of my neck. That episode is now long past, and I have since spent years studying owls of the northern forests. But I often think back to that moment as the beginning, when I first took notice of one of the least studied birds in North America, and gained a direction for my work.

Later on, as I read the literature on hawk owls, I found that most of the information in textbooks and field guides originated in Scandinavia, where the species has long been studied. But I wondered: did it make sense to assume that hawk owls in the New World have the same lifestyle as their cousins in the Old? Aside from some anecdotal reports, few nests in North

America had been described. The most extensive work had been done in the mid-1980s by Kenneth Kertell, now a senior scientist at SWCA Environmental Consultants in Tucson, Arizona. Kertell had studied hawk owl behavior at six nest sites in Alaska's Denali National Park.

My colleagues and I carried out field investigations for the Kluane Boreal Forest Ecosystem Project from 1987 through 1993. In the course of our work, we were able to expand the story of New World hawk owls. We now know that these owls diverge from their Eurasian counterparts not only in aspects of their breeding biology, but also in their behavior, which reflects certain basic differences in the ecology of their boreal homes.

Securing a vole in its talons, a hawk owl pauses before dismembering the prey. When readily available, voles account for most of the hawk owl's diet.

Northern hawk owls are unlike most owls, and, as the name "hawk" suggests, act in some ways like diurnal birds of prey. They hunt in broad daylight and rely on their long tails—shaped more like falcons' tails than owls'—to maneuver in rapid flight. Hawk owls lack the comblike structures along the outer edge of their primary feathers that give most owls silent flight. Their sense of hearing is only so-so for a bird of prey; the keen ability to perceive sound that enables other owls to pounce accurately on prey in the dark is absent in hawk owls.

They are, however, truly hawk-eyed. In a tag-and-release program in Alberta, Canada, field ornithologists "reel in" owls, using a fake mouse attached to a fishing line. Hawk owls are routinely attracted to the small lure from nearly a mile away.

The "northern" in the owls' name denotes their range. Hawk owls live and nest in the taiga, the subarctic band of forests that circle the northern reaches of the globe from Alaska to eastern Canada and from Scandinavia to Siberia. They are nomadic, readily shifting to new nesting areas depending on the relative abundance of their small mammalian prey. And in winter, they sometimes irrupt, or move south of their more usual range in large numbers. The North American subspecies, *Surnia ulula caparoch*, makes occasional winter appearances on farmland as far south as southern Canada and the northernmost regions of the contiguous United States.

Bands of mosquitoes buzzed on the netting around my face. A yellow-rumped warbler grew so accustomed to me that he started to peck insects from my wool pants.

Shortly after my arrival at Kluane I again spotted the bird that had caught my eye on that first day. I watched as it made its screeching call, and then I heard a second, responding hiss. When I raised my binoculars to a snag, or jagged top, of a broken, burned-out tree, I found myself locked in a gaze with a female on her nest.

After that I began spending as many as twenty hours a day in continuous watch and was rewarded with intimate glimpses of the pair's family life. I was transfixed: One day a grizzly walked by about sixty feet away, but we ignored each other. Bands of mosquitoes buzzed on the netting around my face. A yellow-rumped warbler grew so accustomed to me that he started to peck insects from my wool pants. I became part of the forest.

The male owl hunted fairly close to the nest. Every few hours he returned to a low perch with a dead vole or mouse, called out, then decapitated the prey before presenting the remains to the female. He usually dismembered heavier prey at the site of the kill, then delivered morsels directly to the nest. Occasionally he tucked food remnants into tree holes and crannies for safekeeping. When I reached into one hiding place where the male had cached some meat, I grabbed the hind part of a juvenile hare.

Hawk owl eggs, like the two in this nest, hatch after about thirty days of incubation. The parents cater to the owlets in the nest for another three or four weeks. When the owlets fledge, they exercise their new ability to fly by leaving the immediate nest area, but the parents continue to supply them with food for a few more weeks.

In Scandinavia and Russia, hawk owls (subspecies *Surnia ulula ulula*) are classic specialists: in the breeding season 95 percent or more of their diet is made up of small rodents such as mice, lemmings, and in particular, voles. In Denali National Park, Kertell

had discovered that voles made up only 70 percent of their diet; young snowshoe hares and squirrels made up the balance. He suspected that the population of hares influenced the Denali owls' diet. Having held in my hand the bloody evidence that the nesting birds in Kluane were also feeding on hares, I was eager to find out more about the link between hawk owls and hares.

Fortunately, my enthusiasm for hawk owls spread to my colleagues in the long-term ecosystem project. Some of them took censuses of the prey animals in the region, and their data on how the densities of voles, hares, lemmings, and squirrels varied from year to year proved to be the key to part of the hawk owl story. With the help of some volunteers, we found nine nests, the most ever included in a single hawk owl study. We systematically recorded all our observations of hawk owls, and collected and dissected their pellets (small bundles of the regurgitated hair and bones of prey).

The boom and bust cycle of the populations of small mammals is a phenomenon of the taiga and tundra regions of the north. For some still undetermined reason, the numbers of voles, lemmings, and hares soar in some years and plummet in others. Snowshoe hares peak about every ten years. When they were most numerous, so many hares would be hopping along and across the Alaska Highway that I would have to slow my car way down, to avoid a mass slaughter. In contrast, at the low end of a hare cycle, I could walk in the woods for hours and see hardly any hares.

But not all boreal-forest ecosystems are the same: in Scandinavia the populations of small rodents, including various species of voles and lemmings, peak together roughly every three to four years. The biomass, or total organic weight, of those mammals is substantial. And as that biomass cycles between boom and bust, it accounts for more population change throughout the ecosystem than do the biomass cycles of any other vertebrate animals in the system.

Hawk owls were considered vole specialists, but when I reached into the tree hole where a male had cached some meat, I grabbed the hindquarters of a hare.

In North America, however, the population cycles of prey animals are different. At the peak of their ten-year cycle, snowshoe hares, in terms of biomass, "outweigh" all other vertebrate species. Vole populations also peak and crash in North America, but do so more irregularly than those of hares.

White on white: a snowshoe hare in its winter coat. But in winter, even adult hares in camouflage are not immune to attack by hawk owls.

In the Yukon, as in Eurasia, hawk owls seem to prefer voles to other prey. Our statistical analysis showed that they fed on voles significantly more often than they would have if their dietary mix had matched the densities of the available prey. But the diets of Yukon hawk owls are buffered by the availability of other prey. When we began observing nesting hawk owls in Kluane, both vole and hare populations were rapidly increasing. Later, when the vole population crashed but the hare population continued to grow, the hawk owls remained in the nesting area. Voles did drop to about 30 percent of the hawk owl diet by biomass, and young hares and squirrels rose to about 50 percent. In a peak year for hares, the hares edged out the voles as a source of meat for both adult owls and their owlets. But the shift in the owls' diets from voles to hares didn't hurt breeding.

In Scandinavia, hawk owls usually breed only during bursts in the population of voles and lemmings. The average nest holds six or seven young, but at times even larger broods seem to be common. (The record is thirteen, but how many young in that megabrood survived is unknown.) Although investigators have not located as many nests in North America as they have in Scandinavia, hawk owls in the Yukon consistently rear smaller broods than do European hawk owls, between three and five nestlings.

No matter where hawk owls raise their young, breeding coincides with the availability of prey. Owlets fledge in late May or June, just when the boreal forest is teeming with inexperienced young prey animals. At Kluane the hares brought to the nests by parent hawk owls were, on average, only twenty-two-days old.

Hawk owls are also thought to scavenge the remains of adult snowshoe

hares in winter. But we discovered, to our surprise, that these owls, weighing less than a pound, also attacked and killed live adult hares four times their body weight. The hares might have been weakened individuals; even so, the performance speaks to the ferocity and daring of North American hawk owls. The hawk owls of Alaska and Canada are about 6 percent larger than Scandinavian birds. Perhaps their size is an adaptation that increases their success in capturing larger prey.

An intent female tends her triplets, and in the process displays her distinctively long tail.

It seems odd that the hawk owl should emerge as a vole specialist at all, given the owl's strong physical resemblance to birds that prey on other birds. Similarly shaped raptors, such as peregrine falcons and goshawks, are adept at the agile pursuit and rapid capture of birds in flight. But hawk owls, perhaps descended from bird hunters, are skilled aerial predators in their own right. In Scandinavia, during harsh winters when voles are scarce or inaccessible under thick snow, most of a hawk owl's diet can be made up of birds. During winters, our research team in Kluane saw hawk owls kill spruce grouse roughly as big as the owls themselves.

The ability to take advantage of a range of prey animals may give all hawk owls the flexibility they need to survive in harsh and variable northern climates. Compared with the Scandinavian birds, North American hawk owls turn out to be a bit larger, to have fewer young per clutch, and to be less specialized. As investigators gain a better understanding of the species across the entire northern forest, it's becoming clear that this small, fierce, and versatile owl may have been underestimated.

Recently, Wayne Lynch, a Canadian wildlife photographer, and his field assistant Julia Burger witnessed an example of hawk owl predation that had never previously been reported. They were walking to a hawk owl nest near Chip Lake, Alberta, when they flushed an American wigeon. One of the hawk owl pair, perched in a snag above the nest, immediately attacked, hitting the duck in flight and riding it to the ground. Opportunity, even for an unusual meal of waterfowl, had quickly brought out the aerial hunter. The hawk owl, its mate, and their young feasted on duck for days.

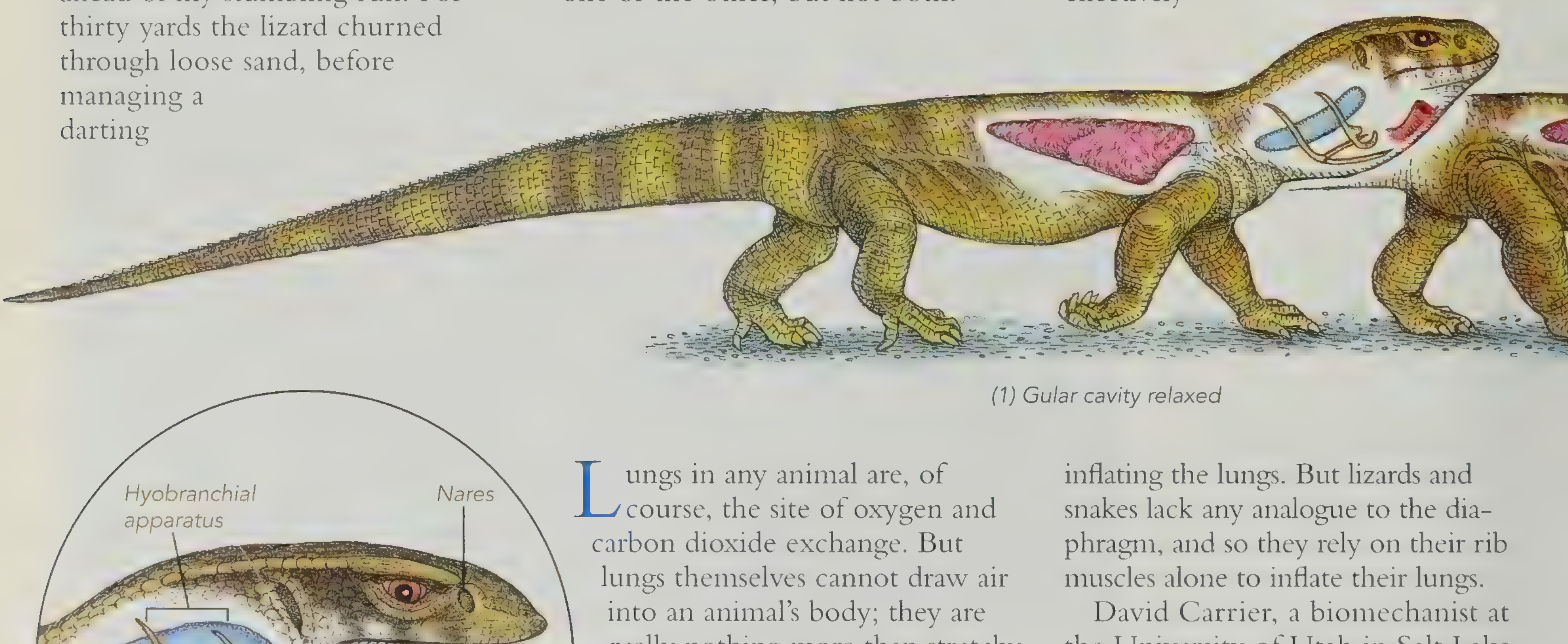
Christoph Rohner is a zoologist and writer who lives in Edmonton, Alberta, Canada.

Monitor Marathons

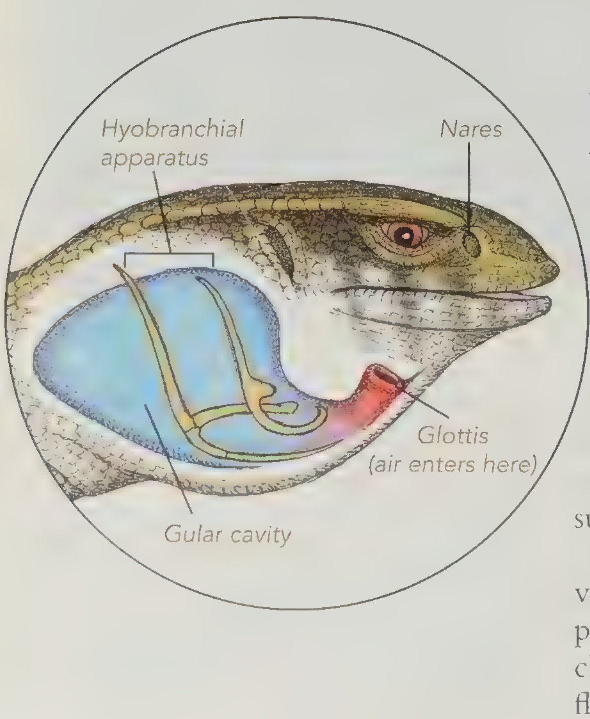
How one group of lizards turns a gasp into a gulp.

By Adam Summers ~ Illustration by Patricia J. Wynne

Making my way down a trail through rosemary scrub in Florida's central sandhills, I surprised a six-lined racerunner (*Cnemidophorus sexlineatus,* so named for the lines that run the length of its body) basking in a wheel rut. I gave chase and the lizard streaked off—easily keeping ahead of my stumbling run. For thirty yards the lizard churned through loose sand, before managing a darting escape under a shady bush. The sprint was impressive, particularly for a lizard less than a foot long, but what was even more amazing was that the lizard had to make its dash without taking a breath. The racerunner's mechanical systems for breathing and running are linked in such a way that the lizard can do one or the other, but not both.



(1) Gular cavity relaxed



Lungs in any animal are, of course, the site of oxygen and carbon dioxide exchange. But lungs themselves cannot draw air into an animal's body; they are really nothing more than stretchy bags that bring air into close proximity with blood. Lungs fill with air when the cavity housing them enlarges, enlarging the lungs as well; the resultant low gas pressure causes outside air to rush in.

Mammals have two systems for ventilating the lungs. The rib muscles power one system: they expand the chest by lifting and rotating the long flat bones to which they attach. The diaphragm, a dome-shaped muscle between the lungs and the liver, powers the second system. It works by pulling the lung cavity rearwards, toward the tail. The diaphragm is a mammalian innovation. Crocodiles and alligators have independently evolved a muscle that pulls the liver backwards, also effectively inflating the lungs. But lizards and snakes lack any analogue to the diaphragm, and so they rely on their rib muscles alone to inflate their lungs.

David Carrier, a biomechanist at the University of Utah in Salt Lake City, observed that a lizard's rib muscles also play a vital role in locomotion: they stabilize the trunk, giving the forelimbs a steady platform from which to operate. But any locomotion also renders the rib muscles nearly useless for breathing; running makes them completely so. Studying the common green iguana *(Iguana iguana),* Carrier confirmed that the rib muscles are active dur-

ing locomotion, and that the lizard holds its breath while sprinting.

Now, any athlete can tell you that holding your breath while running will seriously cut down on your endurance. So Carrier posited that lizards (not unlike me) are restricted to short bursts of anaerobic exercise (less than thirty seconds), followed by prolonged panting to pay back the oxygen debt. (An oxygen debt accrues when muscles work without oxygen; the result is that lactic acid accumulates, and it must be oxidized after the work is done.)

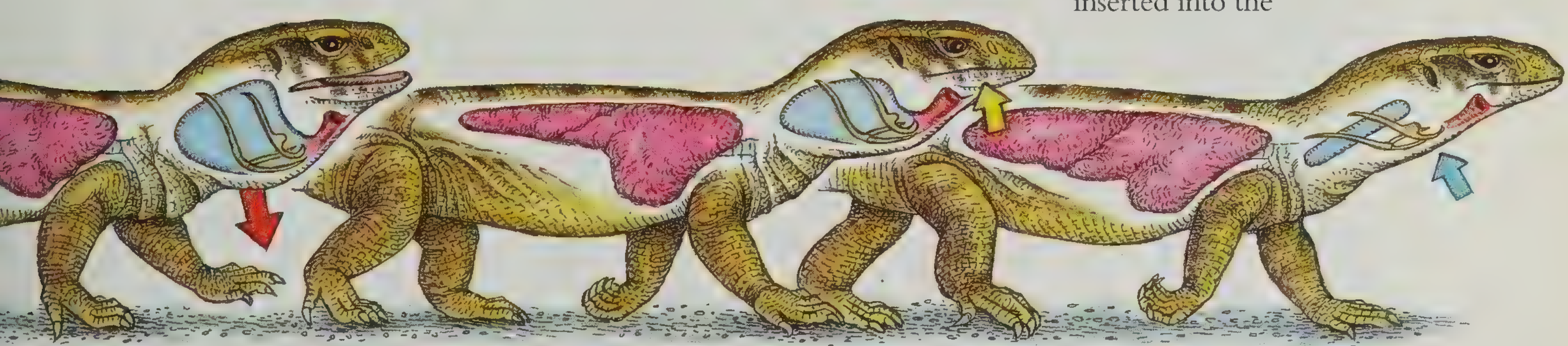
Carrier's hypothesis was controversial, particularly among respiratory physiologists. Other investigators had discovered that monitor lizards—a distant relative of Carrier's iguana—have high metabolic rates. That is, unlike most so-called cold-blooded animals, monitors burn a lot of energy rapidly. A good example is the savannah monitor *(Varanus exanthematicus)*, an African monitor lizard weighing about ten pounds, which spends most of its day patrolling its territory for tasty insects. Its oxygen consumption is as high as that of such mammals as the armadillo, and so the monitor can't afford to hold its breath while moving. On the contrary, the animal should ventilate as often and as vigorously as a metabolically equivalent mammal. But if the lizard can't rely on its rib muscles to breathe while it walks, how does the monitor spend all day walking?

The resolution to this apparent paradox required the joint efforts of physiologists and biomechanists. Tomasz Owerkowicz of Harvard University and Beth Brainerd of the University of Massachusetts at Amherst trained savannah monitors to trot on a treadmill in front of an X-ray machine coupled to a video camera. The X-ray movies demonstrated that, as Carrier had predicted, when the animal ran relatively fast, respiration relying on the subatmospheric pressures generated by expansion of the rib cage was supplanted by a different method of breathing. Long, thin bones below the tongue and in the neck seemed to be causing the lizard's throat and the floor of its mouth to expand and contract: the animal was "gulping" air on the run.

This kind of lung ventilation, well known in frogs and salamanders, is called gular pumping [*see illustration below*]. In fact, the use of head muscles rather than trunk muscles to power respiration predates the evolution of lungs. Fish, for example, pump water across their gills with their head muscles. But until the work of Owerkowicz and Brainerd, gular pumping had not been considered an important factor for lung ventilation in reptiles.

To show that gular pumping is the key to the monitor's endurance, Brainerd and Owerkowicz took a group of treadmill-trained lizards on a road trip to the University of California, Irvine. There, together with the physiologists James W. Hicks and Colleen Farmer, they custom-fitted the animals with small face masks, which enabled the biologists to measure the lizards' oxygen consumption while the animals ran a treadmill. First each lizard ran normally; then a plastic tube was inserted into the mouth to keep the animal's mouth open and prevent gular pumping. And sure enough, when the gular pumping was eliminated, the monitor lizards acted more like Carrier's green iguanas.

Gular pumping has turned out to be far more widespread in lizards than physiologists had previously thought. The monitors, though, with their high metabolic rate, rely on it more than their relatives do. For most other lizards, the drill remains: dash and pant, dash and pant . . . just like me.



(2) Gular cavity extended (3) Mouth and nares closed (4) Gular cavity compressed

Most lizards are like a clumsy person who can't walk and chew gum at the same time; the lizards' handicap, though, is that they can't breathe and run simultaneously. Their rib muscles, which expand the chest during each breath, must also brace the forelimbs during locomotion—especially running. The peripatetic monitor lizards have evolved an alternate route to get air into their lungs. As an animal moves (1), muscles attached to the hyobranchial apparatus (a collection of bones in the lizard's throat) depress the structure, expanding its gullet (2). Air flows into the cavity created; the lizard then closes its mouth and nares (3), and constricts its throat (4), pumping the air into its lungs.

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Patterns in Nature

The new focus on self-organizing processes links such diverse natural phenomena as a zebra's stripes and a mound of termites.

By Scott Camazine

The natural world abounds in eye-catching patterns. Consider the synchronized movements of a school of fish gliding through deep ocean waters; or the coordinated turns and swoops of a flock of starlings whirling among tall trees before coming to rest on a telephone wire. How do all the individuals in the school or the flock avoid collisions with their neighbors? How do they orchestrate their graceful movements?

Other patterns in nature are just as dynamic, but develop so slowly that they appear as snapshots to the human eye: a brief, static moment in a biological process. Think of the striking regularity of alternating light and dark stripes on a zebra's coat, or the reticulations on the surface of the fruiting body of a morel mushroom. Zooming in for a close-up of a slime mold, you can observe the branching network patterns that emerge as the mold grows. On a still smaller scale, magnified several hundred times, similar patterns emerge on the surface of a pollen grain. Intricate reticulated patterns appear in the passageways of the fungus gardens of African termite colonies, and in the crisscrossing trails of foraging army ants.

The living world is filled with striped and mottled patterns of contrasting colors; with sculptural equivalents of those patterns realized as surface crests and troughs; with patterns of organization and behavior even among individual organisms. People have long been tempted to find some obscure "intelligence" behind all these biological patterns. In the early twentieth century the Belgian Symbolist playwright Maurice Maeterlinck, pondering the efficient organization of bee and termite colonies, asked:

> What is it that governs here? What is it that issues orders, foresees the future, elaborates plans and preserves equilibrium, administers, and condemns to death?

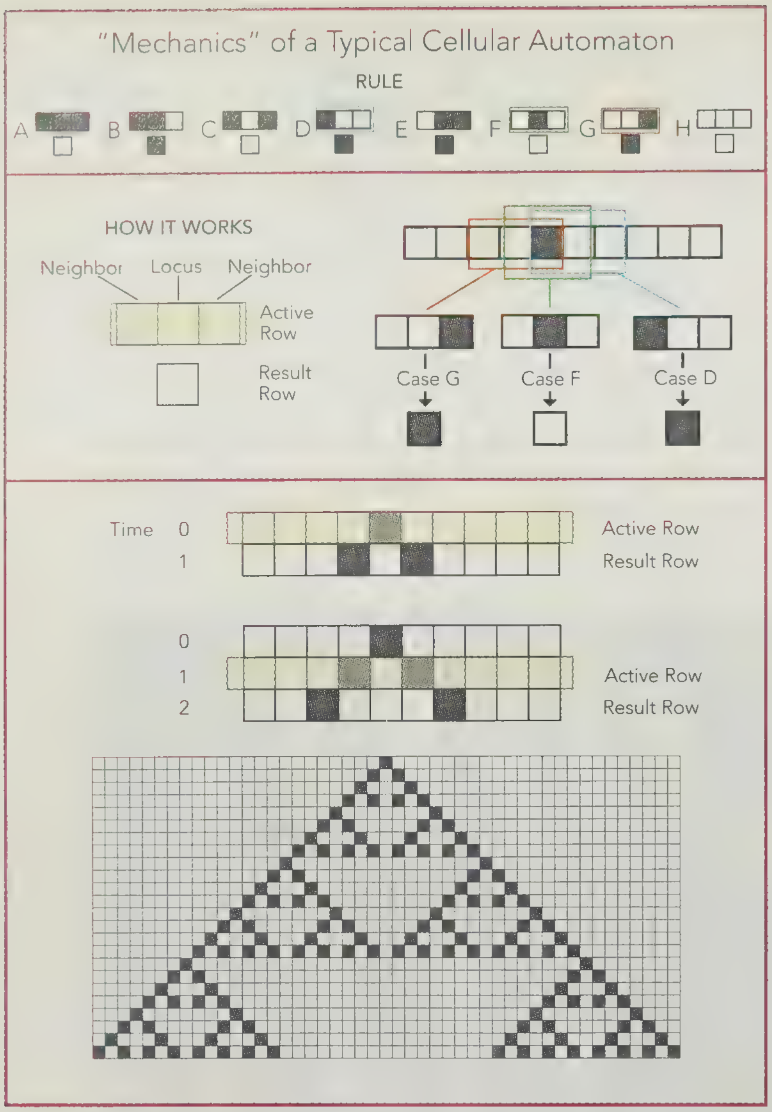
The biblical songwriter in Proverbs marvels at the same phenomenon among the ants, though, more wisely than Maeterlinck, resists the temptation to invoke an intelligent ant:

Go to the ant thou sluggard; consider her ways, and be wise,
Which having no guide, overseer, or ruler,
Provideth her meat in the summer, and gathereth her food in the harvest. (*Prv.* 6: 6–8)

In this instance, science agrees with the Old Testament. Do ants or, for that matter, termite mounds, flocks of birds, or schools of fish have leaders that all the members of the group follow? The answer is, clearly, no. Imagine the kind of oversight that would be needed to build a termite mound. The mound may be thousands or millions of times larger than an individual termite, and the construction of the edifice may take longer than dozens of individual lifetimes. It is simply inconceivable that an overseer guides all those processes. The same holds true of the flock and the school: although their movements are as elegant as the finest choreography, there is no choreographer to direct each bird or fish. The natural world, it turns out, is replete with patterns and processes that exhibit organization without an organizer, coordination without a coordinator.

For some people who come to appreciate this point, it then becomes tempting to attribute such complex patterns and processes to innate behaviors, instincts, or genetic information encoded

Striped markings on the coats of zebras exhibit the kinds of patterns that occur throughout nature, which can be described by simple mathematical tools.



Operation of a cellular automaton is easiest to demonstrate in its one-dimensional form. From a given initial state (row of white or black squares at time 0), a rule specifies how the color of each cell for each of an indefinite number of subsequent ticks of a clock depends only on the colors of a fixed group of neighboring cells; the rule simply itemizes the possibilities. If each step in the evolution is portrayed as a new row of cells, the result, which depends both on the rule and the initial state of the line of cells, is a two-dimensional grid that can simulate a wide range of patterns in nature. The intricate, nested pattern at the bottom of the diagram is the result of applying the rule over the course of twenty-three steps.

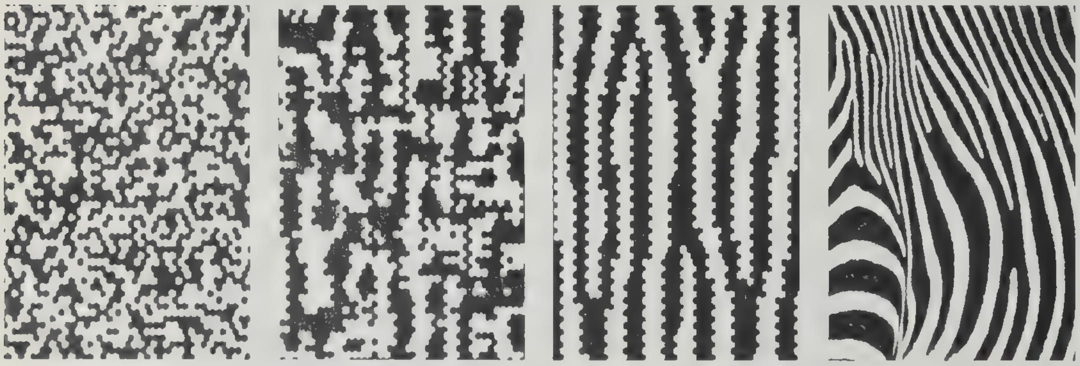
deep within the chromosomes of the organism. But such "simple explanations" are not likely and, in the best of cases, they merely sweep the question under the carpet. What then is the origin of all this stunning complexity?

I have always been fascinated by the natural world, by the strange and complex creatures that inhabit it. As a child, I was drawn to small animals and insects and delighted in their diversity and behaviors. My curiosity took the form of carefully labeled collections of minerals, pressed flowers, feathers, and pinned insects, each specimen with a shape and pattern all its own. I often wondered how such patterns arose, but never found an explanation. Looking back, I think part of the difficulty was that people didn't have the tools needed to explore the question.

In the past several decades, however, a rich convergence of insight has come from a wide range of scientific disciplines, including biology, chemistry, computer science, mathematics, and physics. Out of that mix the field of complex systems emerged. I have followed the exciting developments in this field as a research biologist, physician and photographer.

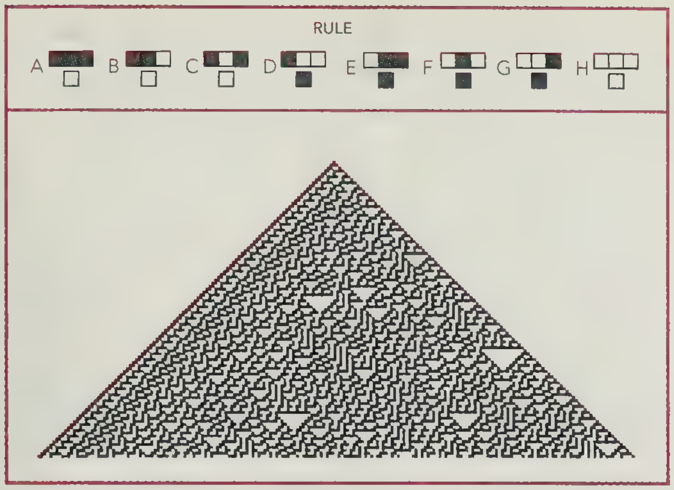
In the years since my childhood, those who study complex systems have learned that many natural patterns share a similar mechanism of formation called self-organization. Self-organization refers to a wide range of processes in both living and nonliving systems. Those processes are characterized by simple "rules" that depend solely on local interactions among the subunits of the system. Yet despite their simplicity and the local range of their immediate effects, the rules and their actions on the subunits give rise to the spontaneous emergence of pattern, order, and structure on a global, system-wide scale.

To put the matter a slightly different way, in a self-organizing system order is not imposed from the outside, by external influences. No architect or foreman holds the blueprint or has a preconceived idea about what patterns will evolve. The patterns that arise are emergent properties, properties that cannot be predicted simply by examining the subunits in isolation. To understand them, the dynamic and often remarkably complex interactions among the subunits must be taken into account.



Zebra skin markings are simulated here by a two-dimensional cellular automaton, from an initial, random distribution of black and white cells (far left). Even with the first tick of the clock a pattern begins to appear (second from left). At the tenth tick of the clock, a stable pattern emerges (third from left), which is quite similar to an actual zebra coat (far right).

Think about the concentric pattern of honey, pollen, and brood that arises on the honey combs of a beehive. Thousands of bees contin-



Entirely different and unpredictable pattern arises as a result of applying a different rule (top of diagram) to the same initial state used in the upper illustration on the opposite page.

ually and simultaneously contribute to the emerging pattern: workers from the field bring in honey and pollen throughout the day; other workers consume the honey and pollen and feed it to the brood; the queen wanders over the combs looking for cells in which to place her eggs; the eggs hatch, become larvae, and finally vacate the cells when they pupate and develop into adults. My research has shown that the bees do not have special "designated" places to put the honey, pollen, and eggs. Instead, they conform to a simple set of what we call rules that guide their behaviors. Nevertheless, the dynamic interactions among all the bees result in the spontaneous emergence of a consistent, stable pattern.

Unfortunately the human mind is poor at predicting what happens when hundreds or thousands of "things" interact with one another, even if the interactions themselves are quite simple. Computers, however, are ideally suited to such a task. One tool for simulating self-organized pattern formation is readily implemented with computer software; the tool is called a cellular automaton, and the patterns that emerge, even from what seem to be the most trivial rules, make a highly convincing rationale for exploring the properties of automata.

One of the first cellular automata to be studied in any depth was the so-called game of life, devised by the mathematician John Horton Conway, now of Princeton University, and popularized by the writer Martin Gardner is his "Mathematical Games" column for *Scientific American* magazine in October 1970.

To understand how the game of life works, imagine a huge grid of squares, entirely covered by checkers, or cells, that are either black or white, "alive" or "dead." Each cell is surrounded by eight neighboring cells whose squares share an edge or a corner with the square occupied by the original cell. A clock ticks the time, and with each tick, the state of each cell on the entire grid evolves to its next state in accord with four simple rules:

1. A live cell surrounded by two or three live cells at time t will also be alive at the next clock tick, time $t + 1$ (it survives).
2. A live cell with no live neighbors or only one live neighbor at time t will be dead at time $t + 1$ (it dies of loneliness).
3. A live cell with four or more live neighbors at time t

Wide range of patterns in nature can be simulated by surprisingly simple rules. Here and on succeeding pages is a gallery of photographs suggesting the variety. Above, wind-blown ripples develop on the surface of the sand in the Gobi desert, in Mongolia.

will be dead at time $t + 1$ (it dies of overcrowding).

4. A dead cell surrounded by three live cells at time t will be alive at time $t + 1$ (it will be born); otherwise, a dead cell remains dead.

When the rules are applied to some initial configuration of live and dead cells (at, say, time $t = 0$), the pattern that arises at time $t = 1$ can be quite unexpected. Moreover, if the same rules are applied to the new patterns of live and dead cells that result at times $t = 1$, $t = 2$, $t = 3$, and so forth, the patterns that evolve over time can be entirely unpredictable. In other words, for some initial patterns, the only way to determine how they evolve under the rules is to watch them.

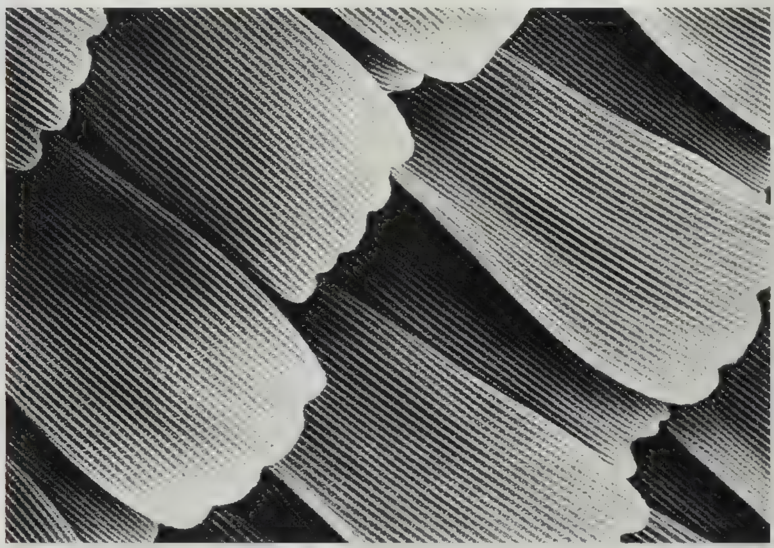
To better understand how such a program works, consider an even simpler version of a cellular automaton. This one begins not with an entire checkerboard of cells (a "two-dimensional" cellular automaton), but instead with just a single row (a "one-dimensional" automaton). In other words, start with a horizontal row of square cells that extends indefinitely far to the left and right. As in the game of life, each cell is colored either black or white. The neighborhood of each cell in the row includes just the two adjoining cells, one to its left and one to its right. And again, as in the game of life, with each tick of a clock, the color, or state, of each cell in the row changes according to some simple rule.

For example, one rule might be the following: a cell becomes black on the next tick of the clock whenever one or the other, but not both, of its neighbors are black; otherwise it remains (or becomes) white [*see upper illustration on page 36*]. A one-dimensional cellular automaton has the advantage that successive patterns can be represented as successive horizontal rows, the "successor" pattern just under its predecessor. The pattern that results is a two-dimensional grid of cells that portrays the evolution of the top row throughout all the ticks of the clock.

Suppose the initial row of cells has a single black cell in the center. When the rule I just defined is applied to that row—the active row—and then to the subsequent rows, a complex pattern develops that is shown at the bottom of the illustration. Applying another rule to the same initial pattern would give rise to an entirely different set of successive rows [*see upper illustration on preceding page*].

It is difficult to convey the intricacy and dynamism of even the simplest cellular automaton with a verbal description or even with static diagrams. Curious readers can visit Web sites where they will be able to watch "home movies" of cellular automata as they evolve:

Yellow morel, black morel, and half-free morel



Scales on the wing of a painted lady butterfly, x400

www.radicaleye.com/lifepage
www.math.com/students/wonders/life/life.html

To see bird flocking simulations visit
www.red3d.com/cwr/boids/

Also visit StarLogo at these three sites:
education.mit.edu/starlogo/
www.kasprzyk.demon.co.uk/www/ALHome.html
lachlan.bluehaze.com.au/alife.html

As with all self-organizing patterns, the main feature of cellular automata is that they are based on a simple set of rules, and they use only local information to determine how a particular subunit evolves. But programs such as the game of life or the one-dimensional cellular automaton just described, while suggestive, lack direct biological relevance. If rules are to be useful for understanding the patterns in real life, such as the stripes of a zebra's coat, they must be different rules.

The zebra's coat alternates in contrasting areas of light and dark pigmentation. In technical jargon, the pigmentation reflects patterns of activation and inhibition—apt terms because of the dynamic process that generates the pattern. Cells in the skin called melanocytes produce melanin pigments, which are passed into the growing hairs of the zebra. Whether or not a melanocyte produces its pigment appears to be determined by the presence or absence of certain chemical activators in the skin during early embryonic development. Hence the pattern of the zebra's coat reflects the early interaction of those chemicals as they diffused through the embryonic skin.

With a new set of rules, a two-dimensional cellular automaton can readily simulate the pattern of the coat and so shed light on the mechanism of pattern formation in the zebra. Return to the square grid and randomly place a black cell or a white cell on each square. The grid will look something like the leftmost frame of the lower illustration on page 36. Assume that each black cell represents a certain minimum level of pigment activator. Such a random array of activator or its absence is thought to be the starting point for the early development of coat patterns.

Now apply another simple rule, based on the following underlying physical effect: activator molecules that are near each other strengthen and mutually reinforce their effect. At the same time, they diminish the effect of activators that are farther away, inhibiting their ability to activate their own nearby neighbors.

In this example, as in the game of life, each cell can be either on or off, black or white. And again, with each tick of the clock, the cells interact with one another according to a rule that reflects the underlying physical reinforcements and inhibitions, and switch their states appropriately. As the regions of activator compete with one another through their local interactions, a regular pattern develops. What emerges is a self-organizing pattern that looks very much like the skin of the zebra [*see the remaining three frames of the lower illustration on page 36*].

Similar patterns occur in the brain. As the embryonic brain develops, competing influences from the right and left eye determine where connections are made in the back of the brain, the visual cortex. Clusters of neurons from one eye or the other dominate portions of the cortex in a distinct pattern. The pattern is thought to develop because the neurons from each eye compete with one another for space. Initially, the neuronal projections coming from the left or right eye are slightly different, a difference that presumably arises at random. The rules of the competition have the same general form as the rules of activation and inhibition of zebra coat pigment. Projections of the neurons from one eye stimulate and encourage additional projections from the same eye. At the same time, those projections inhibit the development of projections to that area from the other eye. This local competition for real estate in the brain results in a pattern of stripes reminiscent of those of the zebra.

Wrinkle pattern formed by a coat of varnish on a wooden surface

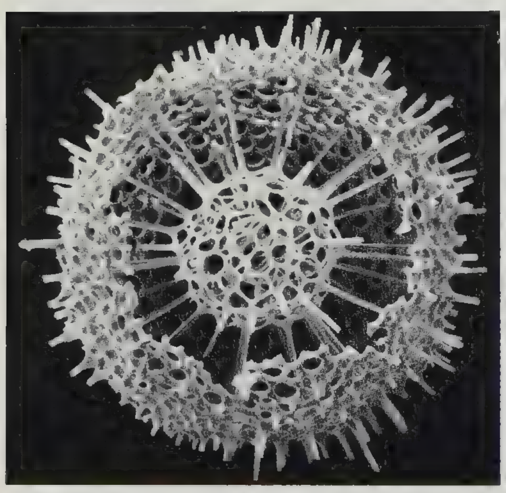
Plasmodial slime mold (Physarum polycephalum) *growing on a leaf.*

Self-organizing patterns extend to the nonliving world as well. They appear in mineral deposits between layers of sedimentary rock, in the path of a lightning bolt as it crashes to the ground, in the undulating ripples of windblown sand on a desert dune. When the forces of wind, gravity, and friction act on sand dunes, the innumerable grains of sand ricochet and tumble. As one grain lands, it affects the position of other grains, blocking the wind or occupying a

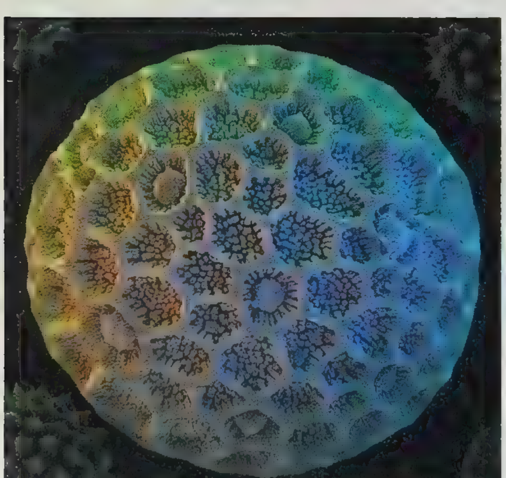
site where another grain might have landed. Depending on the speed of the wind and the sizes and shapes of the grains of sand, this dynamic process creates a regular pattern of stripes or ripples.

Similar patterns arise accidentally on painted surfaces exposed to harsh weather. Paints and varnishes are designed, of course, to adhere permanently and evenly to a surface. Nevertheless, heat, moisture, and sunlight often combine to lift the paint off the underlying surface, causing the paint to crack or buckle. As a patch of paint begins to pull away from the surface, a dynamic tension—between the forces causing the paint to buckle and wrinkle and the adhesive force between the paint and the surface—develops at that spot. The more paint that pulls away, the weaker the adhesive force exerted by the paint nearby that is still sticking to the surface.

Cabbage



Radiolarian, x120



Polygonum pollen grain, x900

The result is a runaway situation but with a countervailing effect. At some point, the dynamic tensions begin to split the paint that has already pulled away. Once that happens, the tensions on the paint far from the split, still adhering to the surface, are reduced. The result is a pattern of buckling ridges.

The runaway process and its countervailing effect, so prominent in the example of the paint, are also key parts of the way patterns form in zebra fur and in sand. The runaway process is also called positive feedback: just as in a snowball rolling down a hill, more leads to even more. In the zebra, an elevated level of activator in the skin leads to more activation nearby, and so to the production of even more melanin pigment. Sand dunes develop ridges when the wind deposits a chance accumulation of sand grains. One small, almost insignificant ridge becomes amplified because it acts as a barrier, promoting the accumulation of even more grains of sand on the windward side of the ridge.

But if positive feedback operated alone and unchecked, there would be no pattern. The zebra would be entirely black; the sand dune would have no ridges. What comes into play is a second kind of process called negative feedback, in which more leads to less. Negative feedback puts the brakes on processes with positive feedback, shaping them so as to create a pattern. The presence of an activator in the zebra skin inhibits pigment production in nonadjacent skin patches and the zebra ends up as a mixture of black and white. (A similar mechanism may also explain the uniform coat of spots in a leopard, formed from islands of high activation.)

Self-organized patterns often arise in living systems because evolutionary processes can build the patterns so economically. The location and branching of each and every marking of a zebra need not be explicitly specified by the limited genetic information carried by DNA. Instead, all that needs to be genetically coded are the characteristics of the interacting molecules. Those characteristics determine just how the molecules act upon one another—what we interpreted as the "rules" that govern the positive and negative feedback processes of the underlying activators that are distributed across the embryonic zebra's skin.

A second economy is an explanatory one: there is no need to invoke a different process to explain each of the many different striped and spotted patterns that occur on the surfaces of mammals, fish, and insects. All such patterns arise through similar developmental pathways. A particular pattern simply emerges from the ways in which certain substances activate or inhibit one another's effects on the formation of pigment.

In nonbiological physical systems, self-organized patterns are epiphenomena that have no adaptive significance. There is no driving force that pushes cloud formations, mud cracks, irregularities in painted surfaces, or spiral waves in certain chemical reactions into developing the striking patterns they exhibit.

In biological systems, however, natural selection can act to favor certain patterns. The particular chemicals within the skin of the developing zebra diffuse and react in such a way as to consistently produce stripes. If the properties of the zebra skin, or the composition of the chemical activators, were

even slightly different from what they are, a pattern would not develop. But in the course of evolution, the specific properties that result in precisely the kind of stripes that zebras possess were selected for and have persisted. One advantage of this pattern of disruptive coloration seems to be an effective adaptation to the presence of biting flies. The visual system of the tsetse fly is particularly sensitive to large blocks of contrasting color. A large black animal on a background of uniformly light-brown savannah is more easily recognized as a potential meal than is a pattern of fine black-and-white stripes.

Zebras' coats are just one example of the adaptive advantage of self-organized patterns. Such patterns also come into play on the folded, reticulated surface of the morel mushroom or on the lining of the stomach. In both those cases, the large surface area, a consequence of the folding, is an advantage: for producing spores in the first case, or for absorbing nutrients in the second.

Yet not all patterns that occur in nature arise through self-organization. A weaver bird uses its own body as a template as it builds the hemispherical egg chamber of its nest. A spider creates its sticky orb following a genetically determined recipe for laying out the various radii and spirals of the web. A caddisfly larva builds an intricate hideaway from grains of sand or other debris carefully fastened together with silk. In those cases, the building of structures does indeed involve a little architect that oversees and imposes order and pattern. There are no "subunits" that interact with one another to generate a pattern; instead, each of the animals acts like a stonemason, measuring, fitting, and moving pieces into place.

Windflower, Anemone coronaria

Finally, what about the graceful movements of birds and fish? Do they depend on leaders, or are they, too, system subunits that "follow rules" and that move gracefully despite the absence of any leaders to guide the group. Coordinated flocking appears to rely on three behavioral rules for maintaining separation, alignment, and cohesion of flock-mates: steer to avoid crowding or colliding with nearby birds; maintain the average heading of nearby birds; and move toward the average position of nearby birds. Fishes' rules are similar, and they suffice to describe the phenomenon.

It is not easy for human beings to intuit how such a decentralized mode of operation can function so efficiently, because human groups rely so heavily on hierarchical organization. Executive functioning, planning, and decision-making exist at many levels of the hierarchy. Imagine a world without supervisors, administrators, and managers, and many people would imagine sheer chaos. Nevertheless, self-organization in nature is efficient, economical, and ubiquitous. It is one of the least known, yet most powerful, devices for achieving pattern and order in the world. □

EDITOR'S NOTE: The looting and destruction that have befallen ancient artifacts from the museums and archaeological sites of Iraq are a calamity for civilization. The photographs on these four pages depict only a handful of the glories that had been unearthed in recent centuries; it is too soon to say with any certainty whether the items pictured here are safe or missing—or whether, if missing, they will somehow yet turn up.

In February 2001, *Natural History* published the article "Robbing the Archaeological Cradle," by John Malcolm Russell, a professor of art history and archaeology at the Massachusetts College of Art in Boston and a leading authority on the antiquities of the Near East. Passages adapted from Russell's article, which provide cultural and historical context for the artifacts, are presented here (italic text). David Keys, a freelance journalist based in Middlesex, England, who specializes in archaeology, has contributed a report about the looting and the early responses to it.

The "Mona Lisa of Nimrud," possibly Ishtar. Ivory plaque of Phoenician workmanship, found in the Assyrian palace at Nimrud. Late 8th century B.C.

Uruk (Warka) cult vase. This three-foot-high vase has five rows of limestone bas-reliefs depicting the abundant fields and flocks of the city-state of Uruk, water, corn growing from the water, sheep, men bearing offerings to the temple, and the king presenting them to the Goddess Inanna (Innin). From Uruk, 5th–2nd century B.C.

Lost Time

Damage control in Iraq

Called Mesopotamia by the Greeks, and variously Sumer, Akkad, Babylonia, and Assyria by its own ancient inhabitants, Iraq has an excellent claim to be the cradle of Western civilization. The emergence of complex communities was accompanied by developments such as writing, the wheel, irrigation agriculture, cities, monumental architecture, state-sponsored warfare, organized religion, written laws, kingship, a wealthy class, imperialism, centrally organized production of hand-crafted goods, and large-scale trade. The first eleven chapters of Genesis are set, by and large, in southern Iraq, in the land of Shinar (Babylonia). Eden, *the Sumerian word meaning "steppe," was the name of a district in Sumer, or southern Babylonia. Mesopotamian royal gardens, notably the Hanging Gardens of Babylon, may have inspired the story of the Garden of Eden.*

—JOHN MALCOLM RUSSELL

Winged sphinx. Ivory and gold, Sumerian, 8th–7th century B.C.

Aftershocks

by David Keys

Funeral crown, a golden wreath of leaves and olives. From Uruk (Warka). Hellenistic, early 3rd century.

Lioness killing a man. Phoenician ivory inlaid with lapis lazuli. From Nimrud, 8th century B.C.

Two nude females. Figurative ivory handle, originally with gold foil. From Nimrud, 8th century B.C.

Gold necklace with lapis lazuli and carnelian pendants. Sumerian, 3000 B.C.

Around the world, the initial response to the looting of Iraq's internationally important museums and archaeological sites was, in the catchphrase of the moment, shock and awe. Early reports claimed near-total destruction of the collections in Iraq's National Museum in Baghdad, numbering some 170,000 ancient artifacts. Three weeks after the looting began, paralysis continued to dog the military reaction. Meanwhile, however, an international roster of organizations and scholars had begun to move toward coordinated action.

Subsequent estimates put the losses at roughly 15 percent of the collections, either smashed, damaged, or looted. Despite the disaster in the museum, virtually all 80,000 of the institution's cuneiform tablets appear to be safe, as do most of the precious Mesopotamian cylinder seals. The losses remain devastating, but they fall far short of complete ruination. What is more, in response to appeals by Muslim religious leaders, some of the stolen objects are gradually being returned.

By the end of April, an alliance of leading Western museums and universities had announced a multimillion-dollar initiative to provide expertise and funding for the repair and conservation efforts. But the basic police work—sealing borders, hunting for thieves, tracking down illicit Iraqi antiquities that reach Western art markets—had been left to governments. Cultural institutions could do little more than beg political leaders to devote resources to an effective, aggressive recovery effort.

The looting of the National Museum itself began on April 10 and continued sporadically for several days. Successive waves of looters broke into dozens of rooms. Tens of thousands of documents, photographs, slides, and index cards were scattered over floors throughout much of the building.

Some of the papers had been gathered into piles by vandals who, it is thought, had intended to turn them into bonfires to burn the building down. But they must have been disturbed—possibly by other gangs of thieves. Some looters came equipped with glass and metal cutters and other tools—as well as trucks and vans for hauling away heavy pieces of looted treasure. The better-organized gangs ignored replicas and stole only genuine ancient treasures. And with considerable organization, they manhan-

Couple embracing. From Nippur, 2600 B.C.

Cylinder seals. Late Uruk, Jamdat Nasr period, 2900 B.C.

Prior to the First World War, when the area that is now Iraq was part of the Ottoman Empire, excavations by foreign archaeologists were carried out under permits issued in Istanbul. Mid-nineteenth-century excavators were allowed to export whatever they wished. That is how the British Museum and the Louvre acquired the bulk of their renowned Mesopotamian collections. Stung by the empire's loss of irreplaceable treasures, and anxious to establish Istanbul as a center for the study of ancient art, the Ottoman statesman Hamdi Bey founded the Archaeological Museum of Istanbul in 1881. Thereafter, foreign archaeologists were obliged to share their discoveries with the museum.

After the First World War, Iraq became a separate state, initially administered by Britain. With the energetic guidance of a British official, Gertrude Bell, who advocated that antiquities be retained by the country of origin, the Iraq Museum was founded in 1923 in Baghdad. A decade later, Iraq began to take charge of its own patrimony. A law enacted in 1936 decreed that all the country's antiquities more than 200 years old were the property of the state; amendments in the 1970s eliminated the Ottoman tradition of dividing finds with their excavators. The Iraq Museum, in the heart of downtown Baghdad, now began to accumulate the most important collection of Mesopotamian antiquities in the world. . . .

—JOHN MALCOLM RUSSELL

Bronze statuette of King Sulgi. Neo-Sumerian, 2094–47 B.C.

Musical instrument, gilded and inlaid, with bull's-head ornament. Found in the Temple of Puabi at Ur, 2450 B.C.

Cuneiform tablets. Left: Algebraic-geometrical table of triangles described by a perpendicular drawn from the right angle to the hypotenuse. Right: Algebraic-geometrical problem involving a rectangle whose diagonal and area are given and whose length and width are to be determined. From Tell Harmal, c. 1800 B.C.

dled all the museum's safes into one room—presumably where they had installed their metal-cutting equipment.

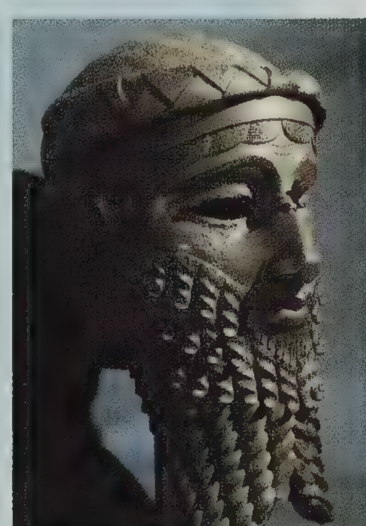
Looters also attacked the National Library, the library of the Ministry of Religious Affairs, and the library at Baghdad University. The museum in the northern city of Mosul—filled with treasures from Nineveh, Nimrud, and Hatra—was also badly looted.

More objects have probably been damaged than have been stolen. Many people outside Iraq have been at a loss to explain the sheer vandalism that Iraqis directed against their own cultural heritage. But as far as the poor of Baghdad are concerned, that heritage had become a surrogate for Saddam Hussein. Images of Hussein dressed as the seventh-century B.C. Babylonian ruler Nebuchadnezzar II stared down on Baghdad's population. Giant helmeted heads at a presidential palace in Baghdad depicted Hussein as the Muslim military leader Saladin. Top Republican Guard divisions were named after ancient Mesopotamian kings.

At the time of the 1991 Gulf War, archaeology was undergoing an extraordinary revival in Iraq. Dozens of foreign and Iraqi teams were working at an unprecedented rate. . . . When Iraq invaded Kuwait in the summer of 1990, virtually all archaeological activity ceased, and the war and subsequent imposition of UN sanctions have left Iraq's patrimony in peril. Not only is almost no money available for the preservation of antiquities, but some Iraqi citizens, squeezed between ruinous inflation and shortages of basic necessities, have turned to looting and selling artifacts from excavated and unexcavated sites and even from museums.

—JOHN MALCOLM RUSSELL

Fluted gold beaker. From the royal cemetery at Ur. Sumerian, c. 2400 B.C.



Bronze or copper head of King Sargon the Great of Akkad (c. 2334–2279 B.C.) or of his grandson, King Naram-Sin (2254–18 B.C.). Found at Nineveh. Akkadian, c. 2250 B.C.

There is, of course, also plenty of anger in Iraq that the Baghdad National Museum was not protected by U.S. forces when they first occupied the city. Just a few days before the invasion, leading academics met with officials from the Pentagon and the State Department to discuss how best to protect Iraq's cultural artifacts, and the National Museum was number one on the list. The academics warned that serious looting would be inevitable unless the museum was properly guarded.

Yet the U.S. military offered virtually no protection to the museum during the first six days of the U.S. occupation. When the museum staff asked for help from a nearby tank crew, the soldiers told them that they had no orders to protect the building. Even when top museum officials appealed directly to senior military officers, no protection materialized.

The lack of a coordinated military response to what Donny George, the director of research at the Iraqi State Board of Antiquities and Heritage, has called "the crime of the century" was still the rule of the day three weeks after the initial occupation of Baghdad. U.S. troops stationed at border posts were still not searching vehicles for looted treasure, noted George, who personally crossed the Iraqi-Jordanian border. "Anyone can take anything and go out of the country," George added. "It's a tragedy." □

Mythical creature with gazelle's head, lion's body, and snake's tail; enameled tile and ceramic brick. Detail from the Ishtar Gate, Babylon. Period of Nebuchadnezzar II, 7th–6th century B.C.

A chimpanzee consumes figs in the Budongo Forest Reserve in western Uganda.

Close Encounters

Mountain gorillas and chimpanzees share the wealth of Uganda's "impenetrable forest," perhaps offering a window onto the early history of hominids.

By Craig Stanford

It's a rare sunny morning in the Bwindi Impenetrable National Park of southwestern Uganda, and a party of chimpanzees is feeding noisily in an enormous fig tree. My colleague John Bosco Nkurunungi and I sit fifty yards away on the other side of the small valley, surveying the scene at eye level through binoculars. The apes, which belong to a group Nkurunungi and I have been observing as part of our field studies, stand upright on thick branches as they stuff themselves with the little fruits. The group's alpha male—we call him Mboneire ("handsome" in Ruchiga, a local language)—eats next to a female we call Martha, and her daughter, May. Grizzled old Kushoto plucks fruit nimbly with his right hand (his left was damaged when it was caught in a poacher's wire snare).

Suddenly the branches in the forest understory begin to sway, and a large, black-haired figure pops partly into view from the green foliage.

"Who's that big guy?" I whisper, refocusing my binoculars. "That's not someone we've seen before." Judging from the size of the top of its head, the new arrival looks to be the biggest chimpanzee I've ever seen.

Peering through his binoculars, Nkurunungi straightens me out: "Craig," he says, "that's not a chimpanzee. It's a gorilla!"

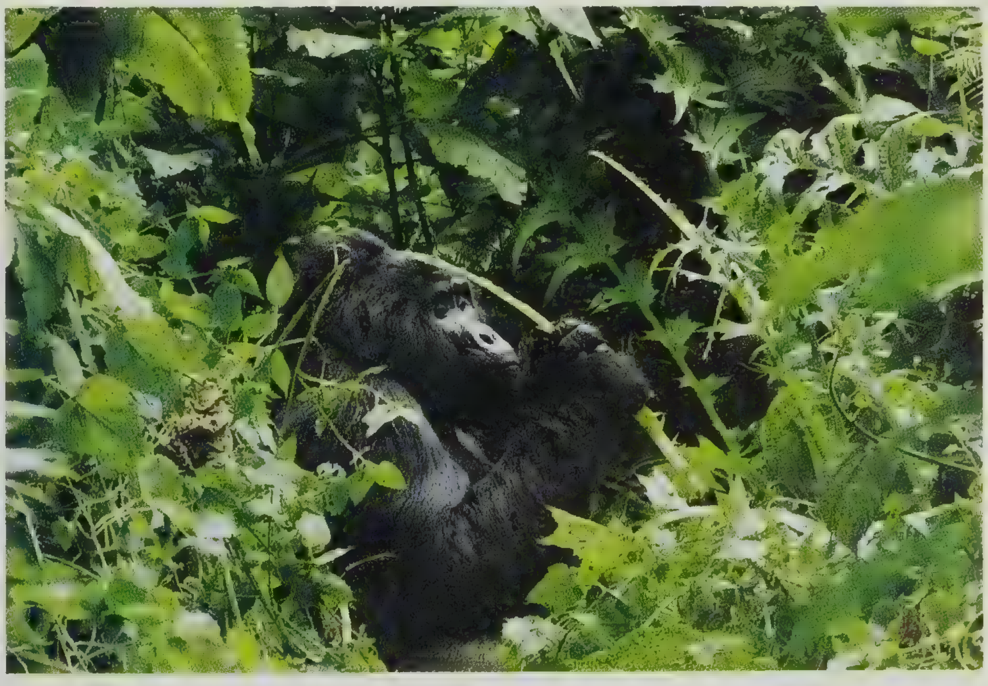
Nkurunungi and I and our assistants in the Bwindi Impenetrable Great Ape Project are well aware that in this forest the ranges of the two ape species overlap. Yet this occasion, in the project's fifth year, is the first time we've ever witnessed an encounter between them. The newcomer, an adult female, emerges from the foliage and sits out in the open on a large branch only twenty feet below the chimpanzees. She's much larger than any of them, and displays the serene and confident demeanor that gorillas always seem to possess. As we watch, she climbs to within ten feet of the chimpanzees, casually plucking figs along the way. Then another gorilla shows up below her, this one a silverback, or mature male, that appears to weigh at least 400 pounds. He joins the female, and the two feed amicably side by side.

For the most part the two ape species pay no attention to each other, but after about twenty minutes the silverback notices us watching from across the way. As suddenly as they appeared, the two gorillas drop out of the tree and then disappear in the dense undergrowth.

As a biological anthropologist, I started the Bwindi Impenetrable Great Ape Project (or BIGAPE, as I like to call it) in 1996, and for seven years now, Nkurunungi, a doctoral student from Makerere University in Kampala, and I have worked together in Bwindi Impenetrable National Park (formerly, the Impenetrable Forest). Our goal is to understand the ecological relations between the chimpanzees *(Pan troglodytes schweinfurthii)* and the mountain gorillas *(Gorilla gorilla beringei)* that share this rugged habitat. Ecological theory predicts that in order for species to co-exist over the long haul of evolution by natural selection, they must avoid head-to-head competition. So two closely related species living in the same habitat typically diverge in some key aspects of their anatomy, behavior, or ecology. Diet is often the main point of divergence, and to find out if that is the case among Bwindi's gorillas and chimpanzees, Nkurunungi and I have had to "walk the walk" of field observation.

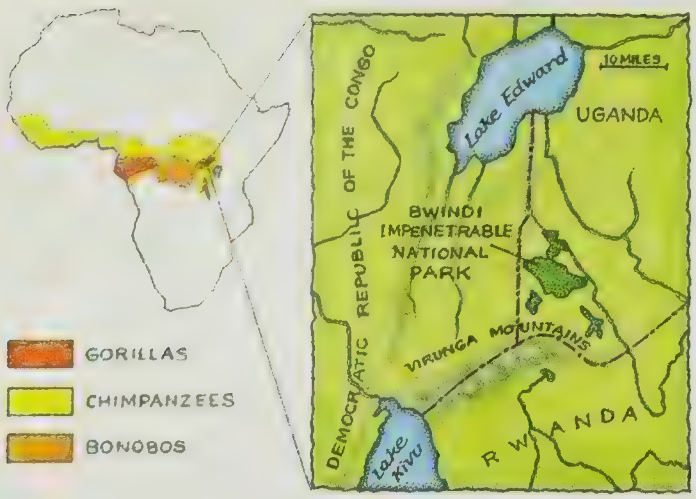
Our interest, though, goes beyond the apes themselves. Anthropologists have long studied the behavior and ecology of the great apes—bonobo, chimpanzee, gorilla, and orangutan—to try to shed light on the lives of early hominids. Investigators have looked specifically at the relations between gorillas and chimpanzees for clues about how early hominid groups may have similarly shared a habitat. And, to be sure, at certain times and places in human prehistory, more than one species of hominid lived in the same habitat.

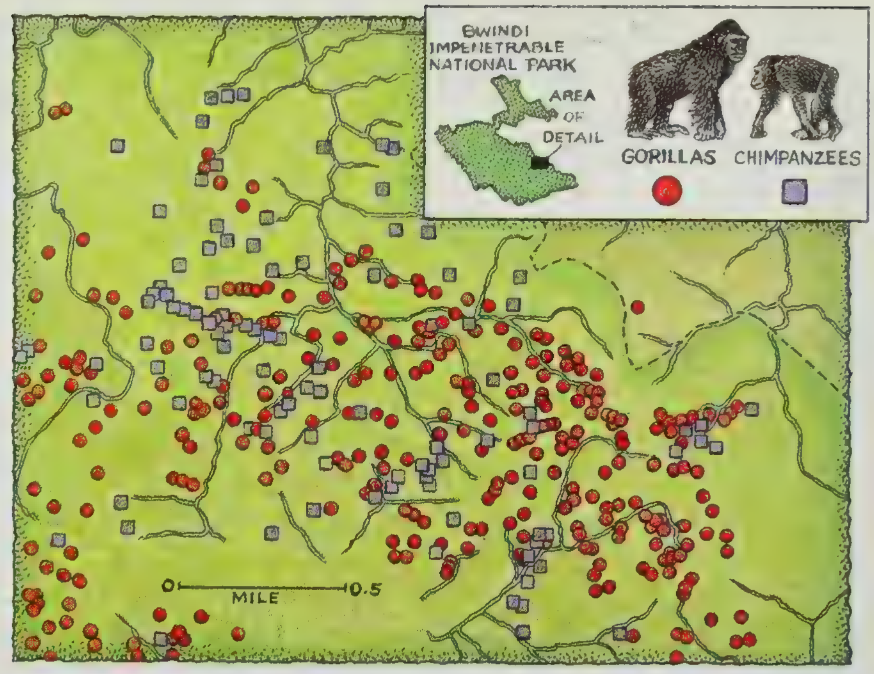
At Olduvai Gorge in northern Tanzania, for instance, *Australopithecus boisei* and *Homo habilis* (the latter an early member of our own genus) occupied the same territory about 1.8 million years ago. Still earlier, about 3.5 million years ago, both *Australopithecus afarensis,* of which the famed fossil Lucy was a member, and the recently discovered *Kenyanthropus platyops* lived in fairly close proximity in East Africa. Anthropologists are keen to determine what kinds of associations such closely related species forged with each other. Did they share their habitat amicably, coming into peaceful contact on a regular basis? Or did they compete—perhaps even aggressively—for food, shelter, and other resources?



In Uganda's Bwindi Impenetrable National Park, a female gorilla dines on wild celery.

The most important clues to the ecological competitions of the distant past are teeth. Often well preserved in fossil records, teeth, their anatomy, and their wear patterns reflect the diet of





Where great apes share a home: Represented in broad strokes, above left, the ranges of the three African apes appear large, and they do overlap. Because of habitat loss, however, the animals are largely distributed in small, scattered populations. In Uganda's Bwindi Impenetrable National Park, both gorillas and chimpanzees roam through the same montane forest. A detail of Bwindi Park, above right, records sites where the two species made their sleeping nests over the course of two years.

their former owner. For example, Olduvai's *H. habilis* possessed unimpressive molars in a modestly proportioned skull. We believe this hominid consumed fruit, leaves, and some meat. In contrast, *A. boisei* had massive molars and a skull with a large bony crest on top, along the midline—the attachment place for formidable jaw muscles. Those features indicate that *A. boisei* was adapted to a diet of either tough and fibrous or hard-shelled foods. Fossil investigators think those dietary differences made it possible for the two human relatives to survive alongside each other for hundreds of thousands of years. Had they instead competed for the same resources, one of them would probably have become quickly extinct.

Beginning with the pioneering studies of wild chimpanzees by the primatologist Jane Goodall and of mountain gorillas by the primatologist Dian Fossey, investigators have watched apes in their natural habitats for more than four decades. As the data accumulated, it began to seem as if the two species occupied quite different ecological niches. In fact, aside from living in tropical forests across equatorial Africa, the two apes were long thought to have little in common. Chimpanzees were portrayed as high-energy arboreal nomads, traveling miles each day to gather a high-carbohydrate diet of ripe fruit supplemented with leaves, insects, and mammalian prey. They ate and made their sleeping nests in tall trees.

Gorillas, in contrast, appeared to be ground-based foragers of wild celery and other fibrous, nutrient-poor foods. Fossey portrayed them as lumbering, sedentary, terrestrial beasts. The idea grew that, although their large brains were impressive, gorillas were the cows—the slow-moving herbivores—of the ape world.

In recent years, however, the general view that there is a wide ecological dichotomy between chimpanzees and gorillas has, to some extent, broken down. As other populations of gorillas have been studied across Africa, it has become clear that Fossey's gorillas, which inhabit the cold, mountainous forest cloaking Rwanda's Virunga volcanoes, lead quite different lives from those of gorilla populations elsewhere. Recent studies show that most gorillas, like chimpanzees, actually prefer fruit, and travel considerable distances to find it. To get other cherished foods, such as fungi and epiphytes, they climb tall trees, just as chimpanzees do. And sometimes they, too, nest in trees, even near the tree nests of chimpanzees. With all those parallels, how chimpanzees and gorillas can be ecologically separated while living in the same habitat is not immediately clear.

Bwindi Impenetrable National Park encompasses some 130 square miles of wet, rugged hills cut into steep ravines by cold rushing streams. The park is one of the last large tracts of montane wet forest in eastern or central Africa. It boasts an extraordinary biodiversity—at least ten primate species live there, as well as nearly 400 species of birds, including some that occur nowhere else in the region.

The population of Bwindi gorillas is about 300. That may seem so small that the population is at

risk of vanishing, but apparently it is stable. The situation is more alarming in other parts of Africa, where gorillas are under much greater pressure from forest cutting, poaching, and, most recently, an outbreak of Ebola virus. In the past five or ten years alone, the total number of gorillas in Africa, believed to have been between 80,000 and 100,000, may have been cut in half. We know less about the Bwindi chimpanzee population, estimated at no more than 200, but across Africa the species faces the same perils.

Using handheld Global Positioning System units, we plot every observation of the two ape species, their sleeping nests, and fruit trees.

Research in Bwindi, however, is not without its drawbacks. The area has suffered several periods of political instability in the past. In early 1999 Rwandan rebels killed a warden and kidnapped fourteen people from a tourist camp, and shortly thereafter they murdered eight of their captives. Since that tragedy, however, the Ugandan government has worked to ensure that the area is secure. Both ecotourism and research are thriving once again.

My colleagues and I are compiling a digital map, aided by Global Positioning System technology, which shows how the chimpanzees and gorillas use the Bwindi landscape. Carrying handheld GPS units, our research assistants plot the coordinates of every observation of the two ape species, noting if an observation is made at a sleeping nest or at a feeding tree. They also map sites where the animals have nested and the position and fruiting season of every major food tree—including the great fig trees that tend to fruit unpredictably. As the mapping has proceeded over a period of years, we have been able to build a digital portrait of how the two apes differ in their use of habitat from month to month [*see illustration on opposite page*]. We can see whether the movements and feeding of one species influences those of the other, and record overlaps in their diets.

The Bwindi gorilla group we are following is quite a cohesive one, made up of thirteen individuals, including two silverbacks. These animals do not follow the lifestyle of their chimpanzee neighbors, and their behavior also differs in key ways from that of the gorillas in the Virunga mountains. In a break from the herbivore stereotype, from January until July, when fruit is most plentiful, our gorillas search for it far and wide. Most of the fruits they eat are the same ones eaten by the chimpanzees, but the gorillas in both Bwindi and in the neighboring forests of eastern Congo exploit a greater variety of fruits than do the chimpanzees in the same habitats.

From August until December, when the fruit supply in the forest is low, the gorillas turn to browsing leafy forest undergrowth, a salad that is low in calories as well as in most other nutrients, but is abundantly available. The consumption of this fallback staple is what seems to distinguish gorillas from chimpanzees everywhere. In the same

Chimpanzees in the Uganda Wildlife Education Centre in Entebbe use twigs to fish for termites. This kind of behavior was first observed in the wild in Gombe National Park, Tanganyika (now Tanzania), by the primatologist Jane Goodall. Bwindi's chimpanzees do not fish for termites, but they do use sticks to probe bee nests for honey.

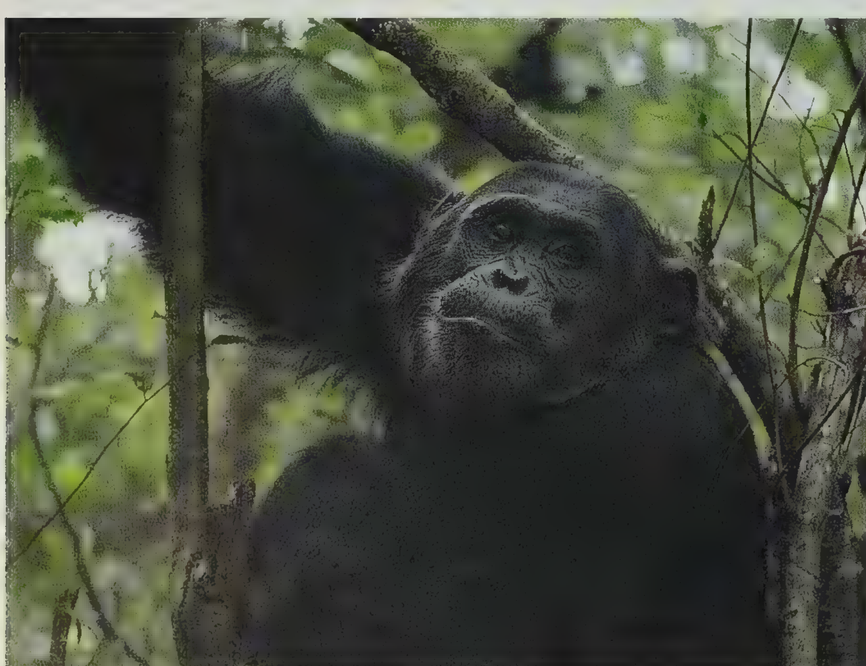
months that gorillas rely on leafy matter, chimpanzees simply expand their search for the increasingly scarce trees with ripe fruit, traveling greater distances each day across Bwindi's hills and valleys.

Another *Gorillas in the Mist* stereotype pictures all gorillas plowing slowly through cold misty meadows of ferns, never bothering to seek the fruits readily available in the upper reaches of the trees. In fact, though, the Bwindi gorillas we observe climb with agility. To see a 400-pound silverback swaying from the uppermost tree branches as he picks figs or orchids and other epiphytic plants for his lunch is a truly impressive sight. Although some investigators have suggested that Bwindi mountain gorillas might possess some genetic adaptation to tree foraging, I prefer a far simpler, common-sense explanation.

The mountainous terrain in Bwindi park extends from 4,000 to 8,000 feet in elevation, whereas Rwanda's Virunga volcanoes, which lie just twenty-five miles to the south, rise as high as 14,700 feet. The lower altitude of Bwindi's mountains makes for a warmer habitat, one that is much more hospitable to fruit trees. In contrast, the habitat of the Virunga gorillas is so cold that few fruit trees (in fact fewer trees of any kind) grow there. Virunga gorillas often have no choice but to stay on the ground and eat herbs. The difference in habitat may also explain why there are no chimpanzees living in the Virungas.

A third feature of gorilla behavior we expected to confirm turned out to be just as misleading a stereotype as leaf-eating and ground-foraging. We suspected at the outset of our study that the chimpanzees would always nest in trees and the gorillas would nest on the ground. Hence nighttime would find them ecologically separated. But at Bwindi, about one-fifth of all gorilla nests are built in small understory trees, which groan under the weight of such massive occupants. And unlike most other chimpanzees that have been studied, the ones in Bwindi occasionally build nests on the ground.

When different early hominid species lived side by side, did they share resources amicably, or did they compete—perhaps aggressively?



Frodo, a male chimpanzee in Gombe National Park. Pioneering work here established that members of the species fashion and use tools, hunt and eat mammalian prey, and engage in other behavior that could not be deduced from the observation of captive animals. As primatologists have fanned out to study additional populations, the variations within the species have begun to emerge.

Our studies of Bwindi apes suggest that the striking behavioral and ecological differences between gorillas and chimpanzees stressed by earlier investigators were, in part, artifacts of the environments where those early studies were done. But our close observations still confirm important behavioral differences that others have noted between the two species of ape. Unlike the cohesive gorillas, for instance, the Bwindi chimpanzees live in the same fluid groups that characterize chimpanzees everywhere. The group we study, which ranges over at least eight square miles, is made up of at least twenty-five chimpanzees. It includes five adult males, plus females and their offspring. At any given moment, however, it is likely to break up into temporary subgroups, or parties.

I noted earlier that chimpanzees and gorillas diverge in their reliance on "fallback" foods, eaten in times of scarcity: the gorillas turn to fibrous plants, whereas the chimpanzees scour more territory for fruits. Another obvious dietary difference is the chimpanzees' love of meat. Virtually everywhere they have been studied—and Bwindi is no exception—chimpanzees avidly hunt and eat monkeys and forest antelope. Although the density of these mammals in our study area is fairly low, we have found that nearly 10 percent of chimpanzee fecal samples contain the bones or hair of prey. In contrast, gorillas do not eat meat at all, and have been only rarely observed in the wild consuming in-

sects. Studies of gorillas in captivity show that their ability to metabolize the fats and cholesterol in meat is quite limited.

In our study area—the high elevation part of the park—the two ape species share roughly the same home range. But within that area the two apes use the forest differently. Chimpanzees are long-distance commuters, covering large parts of their range every week. The gorillas, meanwhile, range over only small portions of the area even in a given month, and it may take them a year or more to fully exploit the available resources. That difference may reduce the ecological overlap between the two species.

Measuring ecological overlap is one thing. But another goal of our study is to investigate whether there is competition between the two apes. That is much more difficult, because it requires showing that one species, through its behavior, is actually reducing the food intake of the other.

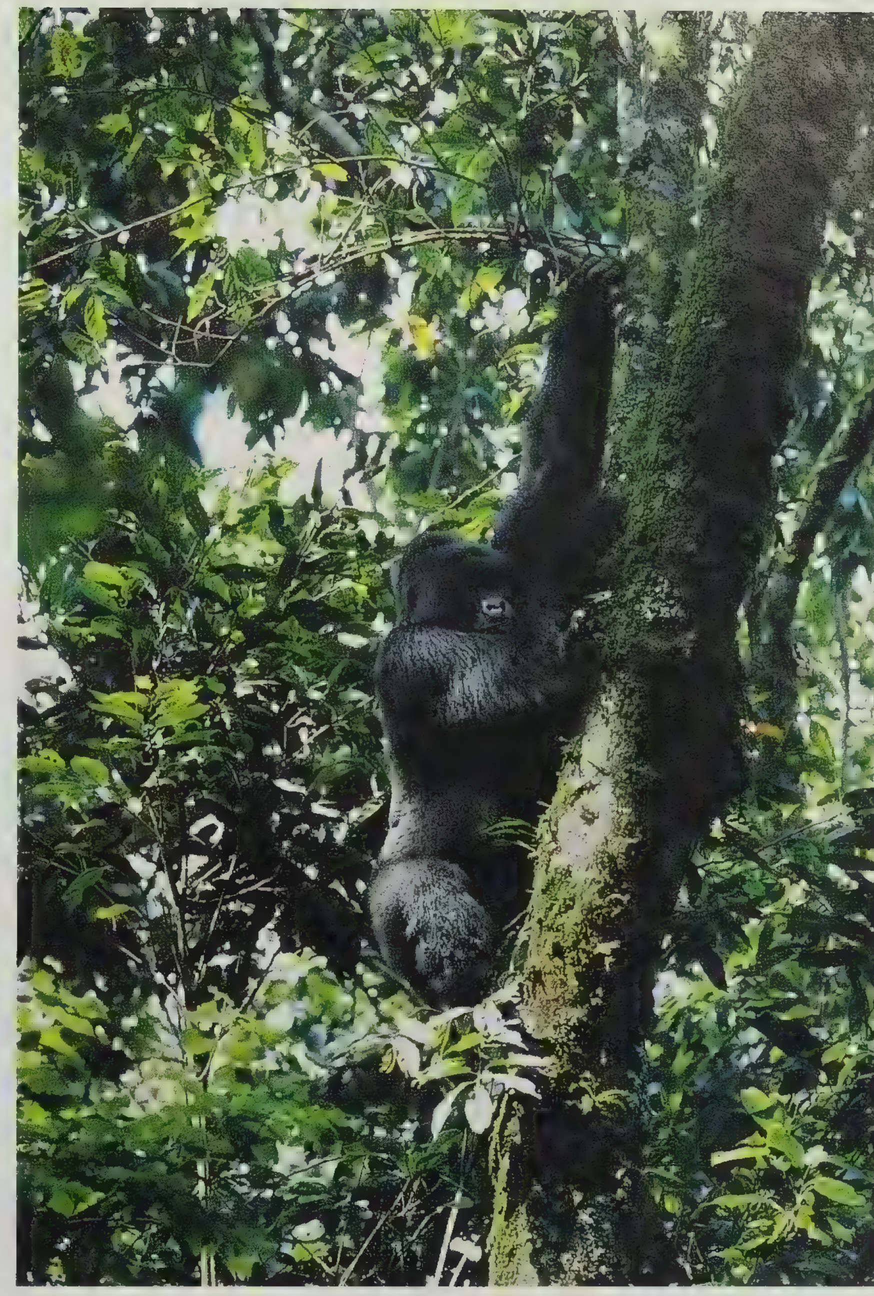
The most straightforward way to demonstrate such competition is to document encounters between chimpanzees and gorillas. We have now recorded four such encounters, in which members of both groups occupied the same tree. Three of them were quite amicable: the gorillas arrived at a tree in which chimpanzees were feeding, entered the tree themselves, fed near their cousins, and then departed.

But one encounter was not nearly so cordial. In April 2002 a party of nine chimpanzees was feeding in a tall *Chrysophyllum gorungosanum* tree (a species of star apple). The tree was laden with the fuzzy brown fruits with their milky-white pulp that both chimpanzees and gorillas relish. As the chimpanzees fed, our research assistants heard gorillas grunting and moving about in the undergrowth below the tree, apparently feeding on fallen fruits. Then a female gorilla, followed by one of the silverbacks, began to climb up the trunk. That prompted two of the male chimpanzees to stop feeding and descend to the first large fork of the trunk, where they obstructed the ascent of the two gorillas with a noisy, hair-bristling, branch-slapping display.

The standoff continued on and off for nearly an hour. All the while, the gorillas remained on the ground or lower branches, calmly watching their boisterous challengers. Finally, the arrival of other research assistants who had been tracking the gorillas startled the chimpanzees, which fled to an adjacent treetop. The gorillas immediately climbed into the *Chrysophyllum* tree and began to partake of the fruit.

This interaction may have been confrontational because *Chrysophyllum* fruit is more highly prized than the figs the apes were eating in the other encounters we witnessed. Although it is risky to generalize from this one observation, the outcome of the contest suggests that in Bwindi, chimpanzees are dominant to gorillas when it comes to competition over food.

It is tempting to imagine, too, that, millions of years ago, *H. habilis,* a direct human ancestor, played chimpanzee to *A. boisei's* gorilla. Perhaps *H. habilis* was the more freely ranging hominid, less inclined to give in to foraging for salad when the going got tough. Perhaps *H. habilis* was the meat eater, smaller but more aggressive. We will never be certain. But we are certain that in African forests today, two of our closest kin are threatened with imminent extinction. They seek only to coexist—with each other, and with us. □

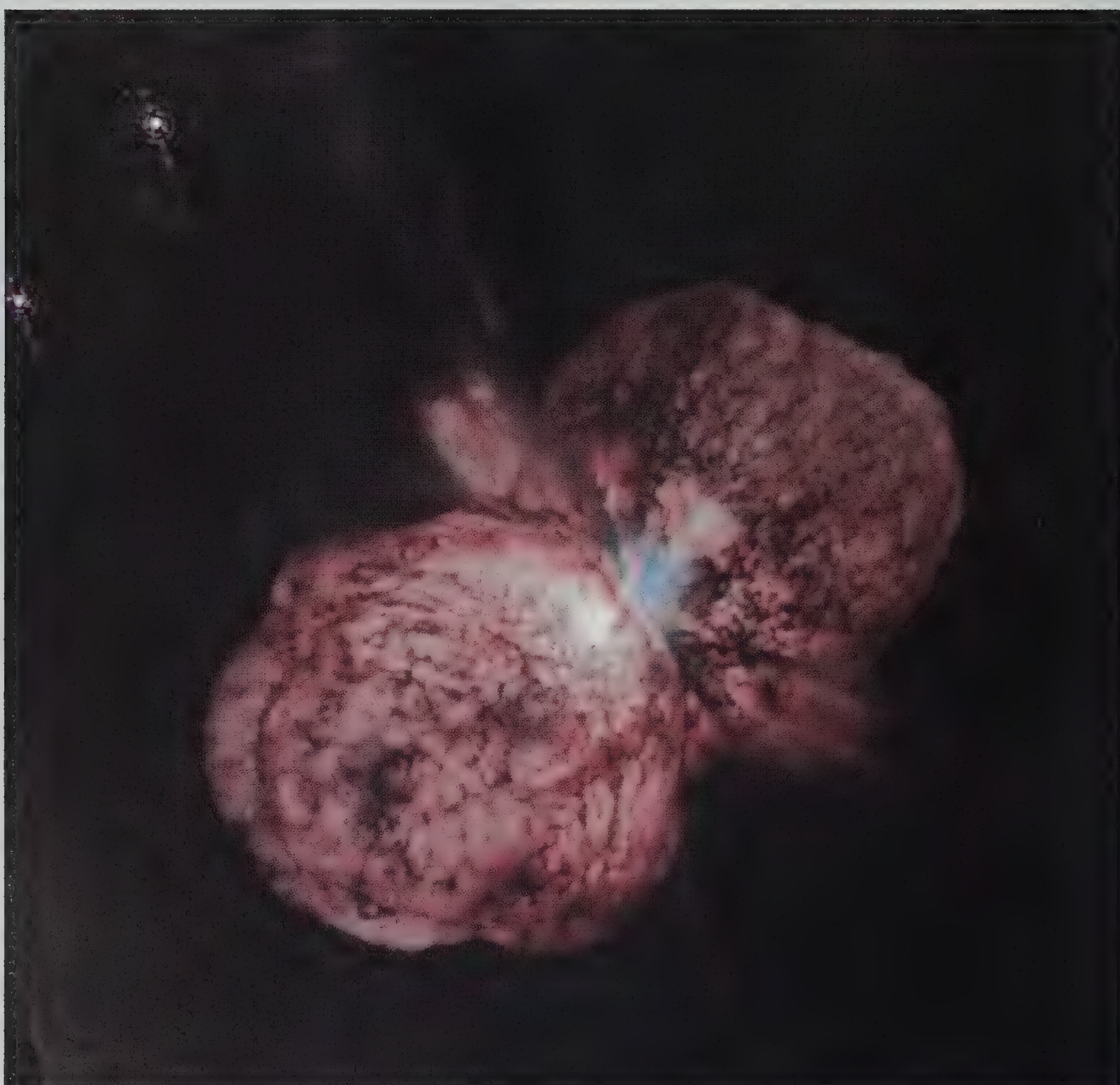


A silverback—a mature male gorilla—climbs a tree in Bwindi. The gorillas in this forest regularly seek out tree fruit and sometimes make their sleeping nests in trees.

Peering at the Edge of Time

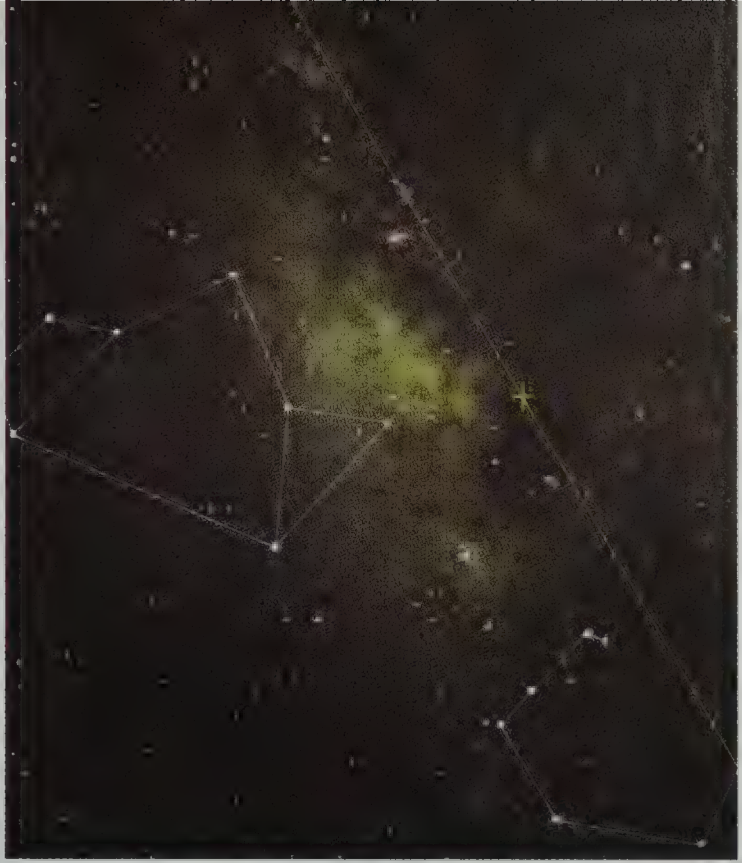
In search of the black hole at the center of our galaxy

By Fulvio Melia



The star Eta Carinae, a hundred times more massive than the Sun, survived the spectacular outburst shown in the photograph, without becoming a supernova—for a time. Expected to expiode soon, it may leave a black hole in its ashes.

Take a trip someday to the town of Port Douglas on the northeast coast of Australia. There, lying on the warm, sandy beach, you will see the evening splendor of the Milky Way arching from horizon to horizon across the cosmic vault. No doubt, as you peer into the starry void, the magnificence of this glorious and overpowering structure we humans proudly call our galaxy will overwhelm you.



The galactic center lies in the constellation Sagittarius (lower right) and is marked here by the cross. The diagonal represents the plane of the galaxy, and the constellation Scorpius is partly outlined to its left. The bright center and diagonal can be seen plainly in the radio image on the left of the next page.

But perhaps even more alluring is another realm, concealed deep inside this vista and shielded from the Earth by a one-way membrane—an event horizon—that eternally separates the world within from the cosmos without. This isolated world at the core of our galaxy is a black hole. First proposed by the physicist J. Robert Oppenheimer in the 1930s, and named by the physicist John Archibald Wheeler in 1967, a black hole is a collapsed aggregate of matter with a gravitational field so strong that the magnitude of the velocity for an object to escape its pull is greater even than the speed of light. And that means no one—not just a stargazer on an Australian beach, not even an astronomer probing the cosmos with the finest instruments known to science—can see it, at least not directly.

But no such technicality has kept astronomers from looking for it. As a species, human beings seek truth and find beauty in the heart of things; the primacy of the central realm beckons. Jules Verne felt it; in his novel *A Journey to the Center of the Earth,* Professor Hardwigg and his fellow explorers encounter an assortment of strange, breathtaking wonders as they approach Earth's core. In early Chinese culture, art and invention were to be found only in the "central kingdom." The supreme oracle of the ancient Greek world sat at Delphi, the *omphalos,* or navel, of the world. The pragmatic Romans echoed the sentiment, holding up their imperial capital city as the center of anti-barbarism. By extension, the heart of something as majestic as the Milky Way must be special indeed, and who would not be drawn to it, teased by what it reveals, tormented with the desire to see more?

The direct observation of a black hole is a chance to see the principles of Einstein's general theory of relativity writ large, and the quest for that sight is what drives astrophysicists like me to look toward the dark behemoth within the Milky Way. But only in recent years have observational methods attained such technological virtuosity that astronomers can focus their attention on the galactic nucleus itself.

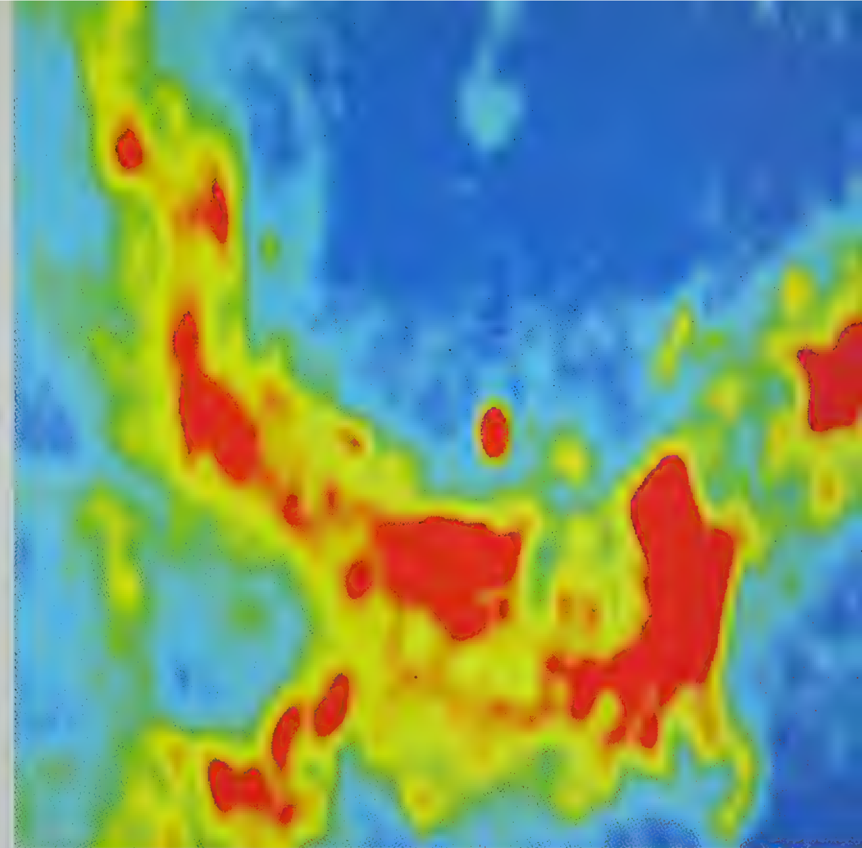
The center of the Milky Way lies in the direction of the constellation Sagittarius, the archer, close to the border with the neighboring constellation Scorpius [*see photograph above*].

Today astronomers tend to name celestial objects and features after the constellation in which they are found; the galactic center is said to lie in the Sagittarius A complex, a large, radio-wave-emitting structure near the constellation. The most unusual object in this region, discovered in 1974, stands out on a radio map of the sky as a bright dot, and, unlike everything else stargazers have seen in the galaxy, it orbits nothing. Rather, it defines the exact center of the Milky Way. Astronomers call it Sagittarius A* (pronounced "ay-star"), the asterisk meant to convey its uniqueness and importance.

The significance of Sagittarius has been unknown for most of the history of astronomy. The reason, in large part, is the intervening dust. That ubiquitous and relentless vagrant of the household is often quite an annoyance to astronomers, and not just because they like tidy laboratories.

The effect of dust on what astronomers see depends rather directly on the color of the light they are trying to sense. Imagine a gondola on the waters just off the Piazza San Marco in Venice. The water, moving in waves, is like the light of space, and the gondola is a grain of dust. Water waves that undulate very slowly, so that crests pass by the boat at long intervals, have little influence;

The bright spot at the center of this radio image, made by the Very Large Array radio telescope, hints at our galaxy's central black hole, called Sagittarius A. The circular glows are supernova remnants; the bright spot glows with the radiation emitted by highly ionized hydrogen interacting with Sagittarius A*.*



Sagittarius A is inside the bright oval at the center of this image, a many-fold enlargement of the bright region at the center of the image at left. Above the oval, near the top, is a red giant star (light blue spot with a comet-like tail pointing toward the top of the page); gas from the red giant is being blown away by the black hole.*

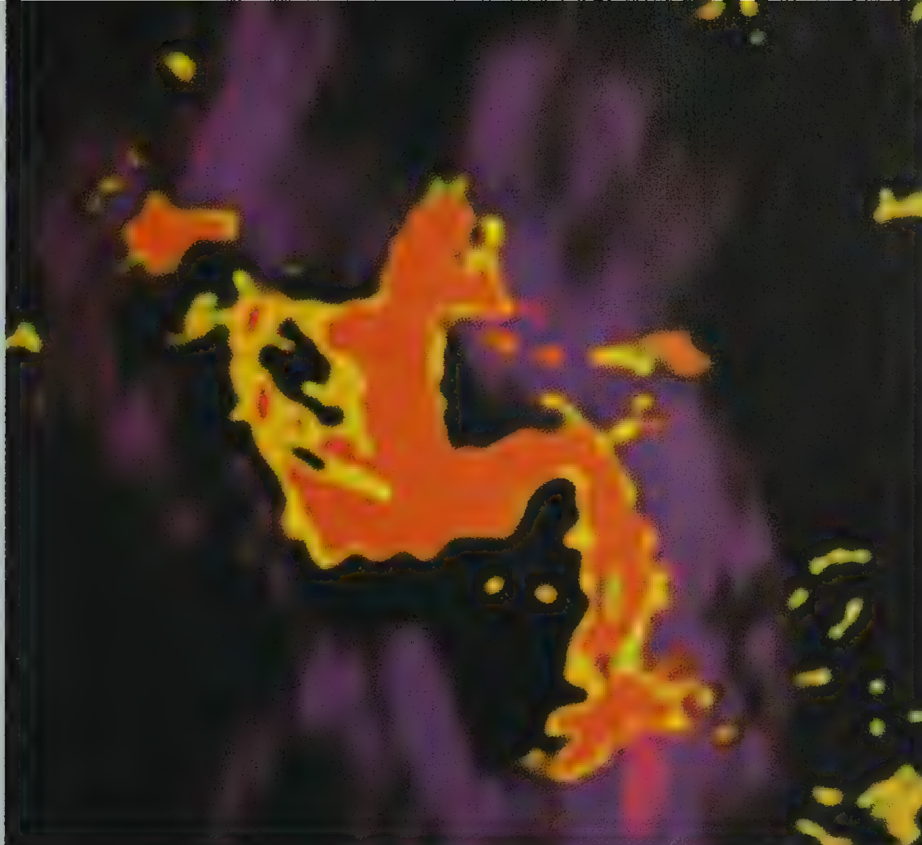
the boat rides peacefully as the waves pass by. Waves whose crests pass at intervals much smaller than the size of the boat—basically ripples—also have little effect; they "bounce" off the gondola with minimal interference. But waves whose crests are separated by a distance comparable to the size of the boat disturb it significantly as they pass, and the gondola disrupts those waves as well.

Coincidentally, the light that our eyes are best suited to see also happens to have the wavelength—that is, the crest separation—for which space dust is the greatest nuisance. Dust dims our view toward the galactic center by a factor of at least 100 million. And so it happens that the heart of the Milky Way, which would otherwise be the brightest patch of nighttime sky, is so heavily obscured by dust that even the most powerful optical telescopes are useless for observing it.

But astronomers can part this dusty veil by collecting light whose wavelength is different from what our eyes can sense. Instruments that detect radio waves, for example, have opened up bright new vistas in the heavens. Radio waves have a crest separation of a centimeter or more, far greater than the size of space dust. Like the slowly undulating water waves flowing past the gondola in Venice, they bypass the dust with no discernible effect. So by looking at the galactic center with a radio telescope, astronomers see a fountain of brilliance instead of what is, optically, a gloomy scene [*see images above and on opposite page*].

Imagine now plunging deeper into the middle of the bright region imaged by the radio telescope, to a point just one-twentieth of a light-year from the center of our galaxy. In that neighborhood such a region comprises as many as a million stars. Furthermore, an examination of the dark, or non-stellar, matter near the galactic center reveals that it harbors even more material that is yet unseen. Here is a territory where physical conditions become exotic, if not extreme. And embedded within a hot cauldron of swirling gases, lurking in the very middle of this inferno, is Sagittarius A*—the deceptively unpretentious face of a colossus with a mass equivalent to 2.6 million Suns.

Nature must surely be a chiaroscurist, a grande dame of light and dark, of shadow and contrast. On the cosmic canvas, astronomers can discern one of the greatest paradoxes in science—that black holes tend to be the brightest objects in the universe. And so it happens that images of the galactic center show not a dark spot, but rather a radiant brilliance. In part, the absence of blackness is a consequence of our remoteness from the central region. At this distance, it is hard to identify features as small as the black hole itself, which should be about as wide as five solar diameters. On an image such as the one at the right on this page, the radius of the black hole would be small indeed, at most one ten-thousandth the size of the



The orange structure in this image is the galaxy's center, glowing brightly with radio waves, superposed on an image of the cosmic dust. The black hole lies just above and to the right of the near-right angle formed by the orange spiral, at the exact center of this image.

central oval visible there. In fact, what blazes away in the center of the Milky Way cannot be the black hole itself—though the nature of the black hole does have something to do with the bright spot's presence there.

What is known is that the outpouring of radiation arises because Sagittarius A* does not exist in isolation from the rest of the universe—even though its interior is forever entombed within an unbreakable seal. Any matter or radiation that haplessly wanders nearby feels its very presence with overwhelming force. Some recently discovered stars swing past it, as close as several light-days, in orbits with periods as short as two decades. Those stars signal the gravitational influence of the black hole with such accuracy that astronomers now know not only its mass, but also its location relative to other objects at the galactic center.

But the stars don't contribute to the central beacon of radio light shining from the black hole itself. Instead, that beacon is a result of Sagittarius A* shining by proxy, inducing the environment to radiate on its behalf, revealing its presence indirectly. Most of the radiation that detectors sense from Sagittarius A* is likely emitted by the glowing, hot plasma—essentially a cloud of charged particles—that moves at near the speed of light as it falls into oblivion past the event horizon. Before disappearing from our universe, the hot plasma glows like the aurora borealis in the Earth's magnetic field, producing radio waves visible to our equipment.

So far, then, our view of the black hole has been, at best, indirect. Yet, as remote as this region of space is, the black hole's shadow will, after all, soon be visible against the backdrop of luminous plasma.

In a series of influential papers published in the early 1970s, a pair of physicists, James M. Bardeen of Yale University and Christopher T. Cunningham of the University of Washington in Seattle, posed what seemed to be a mostly esoteric question: "What would a black hole look like if we had the technology to actually be able to see it?" To address their own question, they had to take an indirect approach; they simulated how a black hole would affect the appearance of a bright object that lay beyond the hole, from the viewpoint of an observer.

Back then, of course, the Hubble Space Telescope was only a twinkle in the eye of Congress. X-ray astronomy—also impervious to interference by cosmic dust—was barely getting off the ground. Single-stage rockets had propelled only crude X-ray detectors into the Earth's upper atmosphere. Radio astronomers would not be detecting a mysterious bright radio source at the galactic center for another year or two. All in all, the prospects for seeing an actual black-hole image like the one Bardeen and Cunningham had simulated seemed rather thin.

To see the black hole is to know that its character is forged in the crucible of general relativity.

In spite of those practical difficulties, the two physicists reasoned that their efforts to simulate the visual effects of a black hole were scientifically useful. Knowledge of what a black hole would look like—if only one could peer through the dense glowing plasma surrounding it—could help astronomers predict how the light emitted in its vicinity might vary in response to changing conditions in the surrounding medium. Armed with

such predictions, astronomers could then look for the variations. Once found, those variations would imply the presence of a black hole. Little did Bardeen or Cunningham know that astronomers would indeed find a means whereby they could hope to see through the hot plasma, virtually all the way to the event horizon of the black hole itself. Observers would after all be put in a position to test the predictions of general relativity for uncommonly strong gravity.

Two decades after Bardeen and Cunningham published their results, astronomers realized that Sagittarius A* is just the kind of object to which those intriguing theoretical ideas might be applied. In 1994 a former U.S. marine and nightclub performer from Arkansas by the name of Jack Hollywood—a nom de plume derived from his earlier persona—decided after several attempts at establishing alternative careers that his true calling was physics. He enrolled in the graduate program at the University of Arizona in Tucson and almost immediately chose general relativity as his field. Hollywood moved effortlessly into a study of the effects of strong gravity associated with all aspects of Sagittarius A*, including its appearance.

A growing sentiment at the time was that stars near the black hole were too far from it—about 50,000 times its predicted radius—for their motions to show the general relativistic effects of the strong gravity near the hole. To this day, in fact, for many astrophysicists, a true appreciation of a black hole's general-relativistic character will come only when astronomers can "view" it directly.

The soon-to-be-minted Dr. Hollywood and his colleagues published several papers outlining how general relativity ought to influence every aspect of what astronomers would see of Sagittarius A*—its radiance, the variations in its luminosity over time, its environment—if only instrumentation existed to resolve it.

But no one could have foreseen how quickly telescopes would improve, particularly the ones that can detect radiation at millimeter wavelengths. In recent years, the work of an international collaboration that includes Eric Agol at the California Institute of Technology in Pasadena, Benjamin Bromley of the University of Utah in Salt Lake City, Heino Falcke of the Max Planck Institute for Radio Astronomy in Bonn, Germany, and Siming Liu of the University of Arizona, has demonstrated the viability of carrying out an experiment to produce an image of the black hole at the center of our galaxy.

Nature must surely be a chiaroscurist, a grande dame of light and dark, of shadow and contrast.

Many astronomers now expect that within this decade an image of Sagittarius A* resembling the computer simulation shown on the opposite page will be attainable with a worldwide array of radio telescopes now under development. Such an image would bring a certain measure of closure to the often fitful, century-long effort to find a way of testing general relativity's description of regions of very strong gravity. Specifically, the image could confirm a bizarre prediction of the theory: that a sufficiently condensed aggregate of matter gives rise to an event horizon. In the image the event horizon would be manifested as a dark, roughly circular "shadow" against the background of glowing gas. The shadow would appear because light emitted by gas directly behind the hole doesn't reach Earth; instead, along the way, it must pass into a region where gravity is so strong that it gets permanently trapped. The process is somewhat analogous to a solar eclipse; the rays propagating from the Sun toward the Earth are blocked by the Moon, and so we see the Moon's shadow, as well as the Sun's visible light all around it.

But there is an important difference between the Moon's capricious attenuation of the Sun's rays and the black hole's absorption of the light radiated by the section of the plasma that lies behind it. Rays that reach the event horizon aren't exactly blocked by it; instead they pass through it, never again to emerge.

Even more pronounced are the differences for light rays passing close to the intervening object. Rays passing near the limb of the Moon are, in effect, moving along straight lines. That is certainly not the case for the light rays passing near Sagittarius A*. The gravitational pull of the black hole is so strong that it severely bends the light. The closer a ray approaches the event horizon, the greater the curvature of its path. So even beams that do not pass through the event horizon are still diverted away from Earth. In consequence, the shadow of the black hole is bigger than its event horizon. Calculations predict the shadow must be two and half times the width of the event horizon itself.

A simulation of the cloud of hot plasma surrounding Sagittarius A shows how general relativity predicts the light from the cloud would be bent by the black hole; the dark central region, or shadow, would appear because light coming from regions near or opposite the hole would be either bent away from our vantage on Earth or swallowed by the hole.*

In the early development of general relativity, the observed bending of light was a real surprise, a major first triumph that later cascaded into several additional, successful tests of the theory. General relativity is almost surreal in the way it mysteriously compels us to accept truths about nature that are hard to appreciate solely on the basis of everyday experience. No other scientific theory so dazzles us with its profundity. Perhaps the reason for its capacity to amaze is that general relativity does something both enchanting and disquieting to space and time, the two main threads of our being. It folds them, twists and pulls them, and then weaves them into a single multifaceted unit.

Our curiosity is piqued, of course, by the chance to see what severe distortions of space-time can do. The discovery of another universe entombed within a black hole, with an alternate metric of reality, would force us to think deeply about our own. The nature of black holes has collected all those musings into one easily identifiable unknown—that's why they excite us, and haunt us even more. And Sagittarius A*, because of its size and its proximity, is our principal gateway into this uncharted territory.

The theory of general relativity mandates a unique shape and size for the region where the bending and capture of light are severe. Soon, those properties will be measurable. No physicist has ever had a comparable opportunity to place the existence of black holes and their strong gravity on such a firm footing. This coming decade may finally give us a view of one of the most important and intriguing scientific discoveries of our time.

Yet the theory is at risk as well. A nondetection of the shadow with sufficiently careful techniques would pose a major problem for physicists' understanding of strong gravity. The mass is undoubtedly there, confined within a region barely the size of the Earth's orbit. But if the mass is not collapsed within itself, general relativity will have broken down at the point where gravity is stronger than it has been in any of the earlier tests. Would such a failure add credence to alternate descriptions of reality, such as string theory, in which gravity is just one element in a purported theory of everything? No one yet knows what steps ought to be taken, should physics be faced with such an unexpected, though not unprecedented, outcome. □

Ages of Aquarius

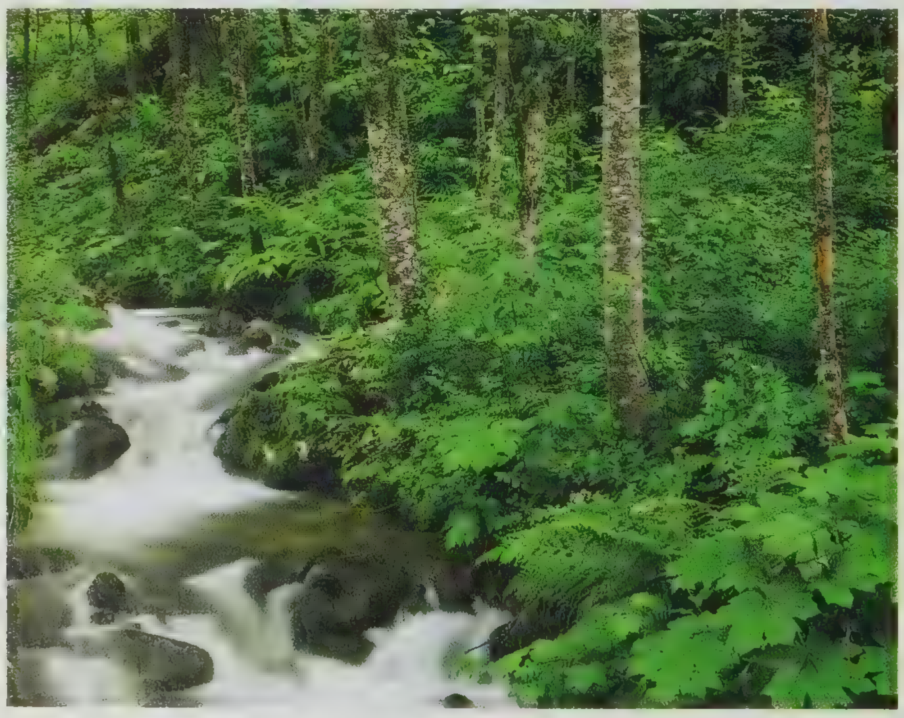
In an Idaho canyon, temperate rainforest plants found refuge from ancient climate change.

By Robert H. Mohlenbrock

In 1968, when Robert Steele and Frederic D. Johnson, both forest ecologists at the University of Idaho in Moscow, explored a remote region along Idaho's North Fork Clearwater River, they found warm, south-facing slopes, cool north-facing slopes, perennial springs, and moist river terraces. They also found stands of forest populated with western red cedar and Douglas fir, as well as with several species previously unknown in Idaho, notably red alder. As they surveyed the vegetation, they were reminded of the temperate rainforests along the northern Pacific Coast, some 300 miles away. Stranger still, some of the plants were associated with Eastern deciduous forests.

Unfortunately, from a botanical point of view, soon thereafter a dam was built about fifty miles downstream, and two-thirds of the area was flooded by the upper reaches of the Dworshak Reservoir. The good news is that six square miles of the surviving rainforest fall within Idaho's Clearwater National Forest and were designated the Aquarius Research Natural Area in 1991. The name Aquarius came from an old campground farther upstream, but how that site got its name no one knows.

The fossil record indicates that before 30 million years ago, temperate rainforests grew in what is now northern Idaho. At that time, to the west lay only shallow seas and tidal flats, making for heavy fogs, ample rainfall, and mild temperatures from the Pacific Ocean that nurtured the habitat. The tree species included dawn redwood, ginkgo, bald cypress, and relatives of present-day sassafras, tulip tree, and magnolia. Tall ferns probably grew in abundance, and mosses cloaked rocky terrain and fallen logs.

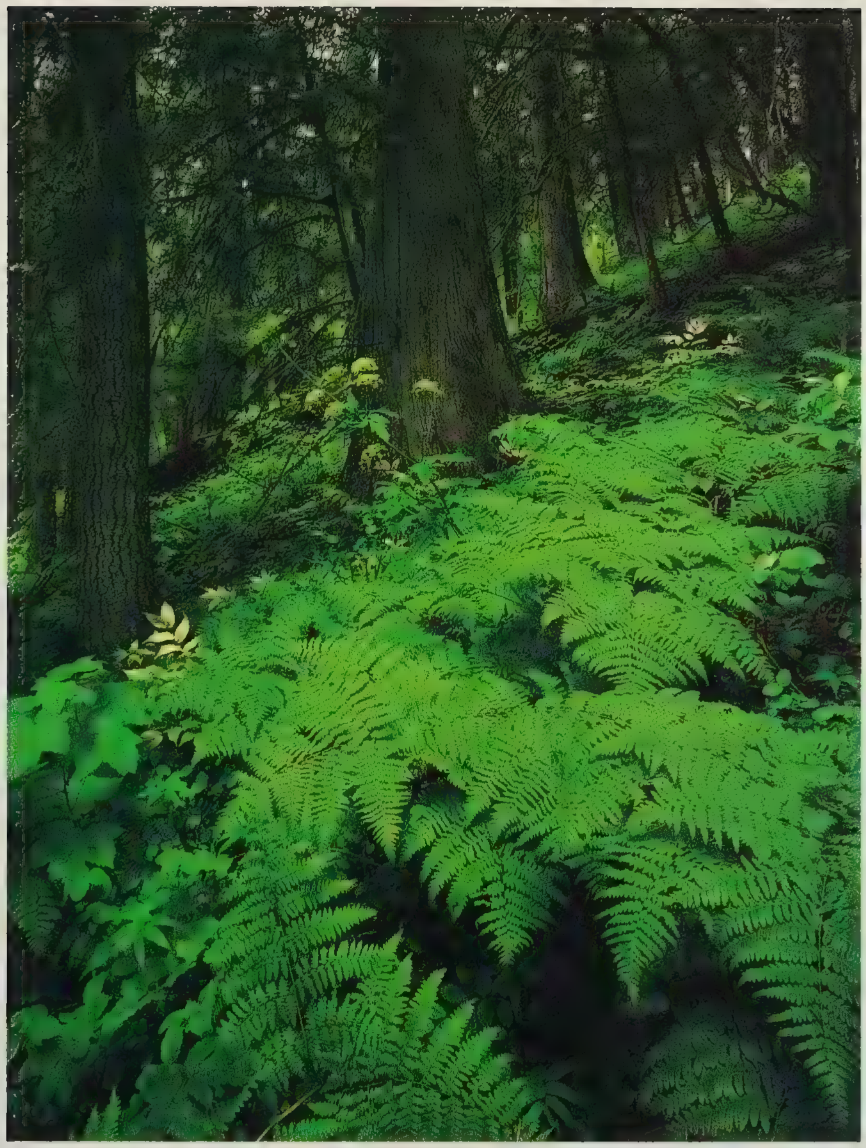


Red alders line Isabella Creek.

Beginning 30 million years ago, however, as a result of plate tectonic events, tumultuous volcanic eruptions uplifted the Cascade Range, blocking much of the Pacific moisture. Temperatures in what is now northern Idaho became more extreme. Some trees, such as red alder, were isolated from members of their species farther west. Others, such as bald cypress and numerous broadleaved trees, disappeared from the region, though they survived in eastern North America. Still other species, such as the dawn redwood and ginkgo, vanished from North America, though they remain to this day in China.

Nevertheless, some temperate rainforest plants persisted in Idaho, finding refuge in canyon bottoms during the ice ages. One such refugium was the canyon of the North Fork Clearwater River. When the last glaciation ended, however, about 12,000 years ago, temperatures rose and the climate became drier. Conditions became generally unfavorable for rainforest plants.

But at least along one river—as discovered by Steele and Johnson—some rainforest plants *did* survive. In large part they owe their lives to the 5,000- to 7,000-foot-high mountains that surround the steep-walled canyon where the plants grow. The mountains capture plenty of moisture—as precipitation and fog—during the growing season. In addition, the fairly low elevation of the river (about 1,650 feet) keeps the temperature from swinging to extremes.



Western red cedar and bracken fern

For visitor information, contact:
Clearwater National Forest
12730 Highway 12
Orofino, ID 83544
(208) 476-4541
www.fs.fed.us/r1/clearwater/

Streamside Within the Research Natural Area flow several streams that empty into the North Fork Clearwater River. The adjacent habitat usually includes red alder, black elderberry, Scouler's willow, black cottonwood, red-osier dogwood, and yellow monkey flower.

HABITATS

Temperate rainforest Western red cedar is usually the dominant tree, but Douglas fir is common on the relatively dry slopes facing south. Grand fir occurs alongside both species. Western red cedar and Douglas fir are prominent on the Pacific coast and in the western Cascades, but are less common in the intervening territory. Other plants that fit with the same disjunct pattern are clustered lady's-slipper, white shooting-star, broadleaf starflower, evergreen violet, Henderson's sedge, and crinkle-awn fescue.

Species of the eastern deciduous forest are northern maidenhair, maidenhair spleenwort, and oak fern. Plants that occur only in or near northern Idaho refugia are Clearwater corydalis, Constance's bitter cress (a lavender-flowered member of the mustard family), and Idaho barren strawberry (whose closest relative is in the eastern United States).

Aquarius Research Natural Area is particularly rich in ferns, including Western polypody, spreading woodfern, oak fern, male fern, bracken fern, and sword fern. Huge lady ferns fill the understory on gentle slopes and on terraces above the river. On moist slopes above the terraces, northern maidenhair replaces the lady fern, and oceanspray populates the shrub layer. One unusual native species is phantom orchid, which is pure white. Devoid of chlorophyll, it derives all its nutrients from fungal associates in the soil. One-flowered Indian pipe, which also grows here, pursues the same strategy.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

Red-osier dogwood in bloom

Voyage of the Barnacle

Darwin paid his dues as a scientist by exploring a miniature universe of marine animals.

By Richard Milner

As a city boy, I once supposed that fossils were as rare as large meteorites and could be encountered only in museums. Eventually I learned that they are almost everywhere: Mesozoic ammonite shells from ancient oceans populate the polished marble of skyscraper lobbies; microscopic plankton skeletons inhabit every piece of chalk; herds of fossil rhinoceroses lie beneath Nebraskan farms.

In 1811 James Parkinson, the English physician and amateur geologist chiefly remembered for identifying the disease that bears his name, marveled that his European contemporaries lived literally surrounded by fossils. In volume one of his work *Organic Remains of a Former World,* he noted that extinct marine organisms "have become the chief constituent parts of the limestone, which forms the humble cottage of the peasant; and of the marble which adorns the splendid palace of the prince." But what Parkinson found even more astonishing was that no one seemed to share his intense curiosity about how and when those organisms had found their way into the building materials of hovels and mansions alike.

Billions of primitive marine animals still share the planet with us today. One of the more ubiquitous of them is the barnacle—the small invertebrate that clings to whales as well as to dock pilings and shoreline rocks. In her entrancing book *Darwin and the Barnacle,* Rebecca Stott, a professor of English at the University of Cambridge, quotes Charles Dickens's *Little Dorrit* on this creature's omnipresence: "Wherever there was a square yard of ground in British occupation under the sun or moon, with a public post upon it, sticking to that post was a Barnacle." Perhaps most human activity directed at barnacles has been devoted to that despised sailor's task—scraping them off ships' hulls.

Stott begins her tale by recalling childhood visits to the seashore, where she first encountered cone-shaped barnacle shells. Each one held a "bizarre inhabitant, a cream-coloured shrimp-like creature, upside down, glued to the rock by its head, fishing for plankton through the hole in its cone with its feathery feet." Stott also came across the stalked barnacles that cluster on driftwood, which some consider a seafood delicacy. She began to wonder: Just what kind of critters are barnacles? Are they mollusks? Crustaceans? How many kinds are there? Where did they come from? How far back can one trace their ancestry? By the time she summoned the courage to order barnacles in a seafood restaurant, she associated them with Charles Darwin, whom she realized was obsessed with the odd creatures.

> ***Darwin and the Barnacle: The Story of One Tiny Creature and History's Most Spectacular Scientific Breakthrough***
> *by Rebecca Stott*
> *W.W. Norton & Company, 2003; $24.95*

In 1831, when twenty-two-year-old Darwin set sail as a fledgling naturalist on HMS *Beagle,* no one knew much about barnacles—and few cared. But young Darwin was, as his uncle described him, "a man of enlarged curiosity." In 1835 he collected a conch shell on a Chilean beach and noticed that there were hundreds of tiny holes in it, which interested him more than the species of the shell itself. He suspected that some small creature had made the holes, although he could see none. Later, under a microscope, he spotted the culprit: a minuscule, soft-bodied inhabitant cemented into the hole by its head and waving its jointed legs in the air. Anatomically it resembled an acorn barnacle. But that creature was defined by its cone-shaped shell.

Darwin had discovered something as yet unknown to science: a rare burrowing barnacle with no shell-house of its own. The questions raised by this creature's anomalies would occupy him for years. As Stott reveals:

> Darwin will carry this Chilean barnacle on a journey around the world, from the South American beach back to London, preserved in a jar of wine spirits. When he has finished finding homes for all the 1,529 species he has collected . . . on the *Beagle,* he will return to the puzzle that the creature's strange anatomy presents; and then he will write this Chilean barnacle's evolutionary biography—a puzzle that will take him eight years to think through.

Eight years, from 1846 until 1854, devoted entirely to barnacles? By 1842 Darwin had already sketched out his theory of evolution by natural selection. But he pushed it all aside, squirreling it away to work on the barnacle riddle. What was so com-

pelling about these invertebrates that Darwin chose to postpone the completion of his major work—*Origin of Species*—for their sake?

Hundreds of books have touched on diverse aspects of Darwin's discoveries: his encounters with finches on the Galapagos Islands; his elucidation of sexual selection, orchid pollination, and the formation of coral reefs; his treatise on the evolution of emotional expression. Barnacle anatomy and classification, however, is an arcane technical field that most Darwin scholars have treated only superficially. Now, at last, Rebecca Stott, albeit a nonspecialist in barnacles, has had the courage and tenacity to make Darwin's barnacles—and their importance—accessible to the rest of us.

Before Darwin's work, these seemingly insignificant invertebrates were as little known to Victorian science as were the tribes from Tierra del Fuego that Darwin encountered on his *Beagle* voyage. Stott describes the naturalist's quiet excitement as he explores the world of the barnacle on his tabletop, his eye glued to a microscope day after day, his large hands manipulating little pins for tearing apart pickled creatures in order to "daily see some more beautiful structures."

She also weaves some of Darwin's personal traumas into the narrative: the heartbreaking loss of his beloved ten-year-old daughter Annie to tuberculosis; his own battles with a mysterious malady while under the care of a quack. Both episodes took place during his so-called "barnacle years." So protracted was his barnacle study that his children assumed it was the normal occupation of every father: When one of Darwin's young sons visits a neighbor's home, he asks his friend there, "Where does your father work on his barnacles?"

Erasmus Darwin—Charles's grandfather and, by some accounts, the first European naturalist to publish a theory of evolution—had believed that all living things were descended from microscopic sea creatures. (Erasmus had even designed a Darwin family crest with the motto *ex omnia conchis,* "all from shells.") His grandson Charles was awarded the Royal Medal

An illustration of barnacle shells from Darwin's 1854 work A Monograph of the Sub-Class Cirripedia, with figures of all the Species

of the Royal Society in 1854 for his work on barnacles—in effect, carrying on a family tradition. Charles not only described thousands of living exemplars, but also compared them with fossil specimens. The result was an evolutionary classification—published well before *Origin of Species*—that showed how hundreds of variously adapted species branched out, over millions of years, from common ancestors. Grandfather Erasmus—who died before Charles was born—would have been pleased.

In the 1830s and 1840s marine invertebrates were enjoying a scientific vogue, and papers about them dominated the zoology section at meetings of the British Association for the Advancement of Science. Among the leading lights of invertebrate research were Thomas Huxley, the naturalist who had devoted himself to crayfish, squid, and jellyfish, and the zoologist and botanist Edward Forbes, who had worked on starfish and medusae. Puzzling over the origin of life, they noted the similarities of form between those marine invertebrates and the early stages of vertebrate embryos. In studies with a microscope, Forbes had shown that hydroid jellyfish known as naked-eyed medusae reproduce not only by spewing eggs, but also by asexual budding, which he found marvelous to behold:

> What strange and wondrous changes! Fancy an elephant with a number of little elephants sprouting from his shoulders and thighs, bunches of tusked monsters hanging epaulette-fashion from his flanks in every stage of advancement! . . . It is true that [naked-eyed medusae] are minute, but wonders are not the less wonderful for being packed into small compass.

Barnacles were at one time grouped with mollusks, but by the 1830s zoologists had shown that the adults, which spend their lives fastened to one spot, develop from free-swimming young, making them more similar to crustaceans. Zoology textbooks of the time also recited a second misconception: that all barnacles are hermaphrodites. Darwin was finding otherwise. Still carefully dissecting them piece by piece, he was discovering that al-

though barnacles do indeed lead bizarre sexual lives, hermaphrodism wasn't always part of the mix. The males of one species *(Cryptophialus minutus)*, Stott tells us, had "quite the largest genitalia [Darwin] had ever seen in the barnacle world." In one of Darwin's descriptions of a *Cryptophialus* penis, he characterizes it as

> wonderfully developed . . . when fully extended, it must equal between eight and nine times the entire length of the animal! . . . [The barnacle] has an orifice at its upper end, and within it there lies coiled up, like a great worm, the probosciformed penis . . . there is no mouth, no stomach, no thorax, no abdomen, and no appendages or limbs of any kind.

This burrowing barnacle group from Chile (which Darwin had at first affectionately named Mr. Arthrobalanus but later christened *Cryptophialus*) seemed at first to be comprised entirely of males, whereas the genus *Ibla,* one of the stalked rather than coned barnacles, seemed to be made up solely of females. Darwin soon discovered, however, that not only were some *Ibla* specimens hermaphroditic, but that in a related species with distinct sexes, what he had taken to be parasites on the females were actually minute males—little more than tubes containing sperm—clinging to the female bodies. Although the male larvae were free-swimming, he wrote:

> at the instant they cease being locomotive[,] larvae become parasitic within the sack of the female, & thus fixed & half embedded in the flesh of their wives they pass their whole lives & can never move again.

Those findings led Darwin to believe he could demonstrate a series of evolutionary sequences from hermaphrodite to separate-sex species. The wide range of sexuality he had seen among sea creatures was so improbable and fantastic that he wondered whether anyone would believe him. "You will think me a Baron Münchausen amongst Naturalists," he once warned a botanist friend, alluding to the eighteenth-century figure known for his impossible adventures. Other scientists investigating this miniature marine universe were similarly astonished; the spectacular spectrum of sexuality they discovered was shocking to Victorians. For the scientists' wives and lady friends, Stott imagines, "hushed parlour conversations about undersea reproduction, the slime and tentacles of marine courtship, were doubtless piquant, grotesque, and erotic."

Darwin had been aware since 1837, when he began the notebooks for his *Origin*, that the creationist doctrine of fixed species would crumble if only he could find extreme mutability within one species. "Once grant that species . . . [of] one genus may pass into each other," he wrote, "& whole fabric [of fixity of species] totters & falls." As it happened, the first genus

John Swain, *Valuable Addition to the Aquarium, Punch,* London 1860

he had chosen to study, *Cryptophialus* (the group that included his burrowing barnacle), would turn out to be the very epitome of mutability, revealing the astounding variability of organisms in nature.

Darwin's friend, the botanist Joseph Hooker, had warned him that "no one has the right to examine the question of species who has not minutely described many." The barnacles won Darwin that right. Through his intense labor with them, he developed an extensive network of correspondents in the scientific community who would later greet his *Origin* with respectful attention. Classifying the barnacles gave Darwin new skills as a dissector, a microscopist, an observer, a classifier, and a theoretician. Moreover, he had satisfied himself that nature produced no sharp lines of demarcation between varieties and species.

"My life goes on like Clockwork," he wrote his old captain, Robert FitzRoy, during the barnacle years, "and I am fixed on the spot where I shall end it." Stott sums up his forty years at Down House, his country estate in Kent, with an apt metaphor:

> The larval Darwin has metamorphosed. He has found his rock. Anchored to it, he will stay here like the adult barnacle, for the rest of his days, reproducing himself, fishing with his feet as the tide comes and goes. And his life . . . as regular as the tides."

Richard Milner is an associate in anthropology at the American Museum of Natural History and a contributing editor of this magazine.

By Laurence A. Marschall

Stiff: The Curious Lives of Human Cadavers
by Mary Roach
W.W. Norton & Company, 2003; $23.95

Warning: Do not read *Stiff* lying down. First of all, it's a trifle unsettling to eyeball its dust jacket while supine; the toe-tagged soles on the cover make you feel as if *you* are the body lying in a morgue. Second, if you share your bed with a dozing partner, you may endanger your relationship by laughing yourself silly. In her own edgy way, Mary Roach is an extremely funny science writer.

Roach doesn't flinch when confronted with the no-longer-living, because she finds the macabre so frequently absurd. When she visits a face-lift workshop at a university medical school, for instance, she discovers that a disembodied human head is included in each participant's price of admission. Walking between the tables, she confronts rows of these dissection specimens from donated cadavers, each neatly arrayed in a roasting pan. It's a bit less unsettling, she thinks, to imagine the lab as a rubber-mask factory, and the surgeons as sculptors—which, in a way, they are.

The absurdity of "cadaverology," you realize, lies in the mixture of the mundane and the bizarre one encounters in the world of corpses. Working with dead bodies, we all dimly acknowledge, has many practical uses—yet, like sausage-making, it's best not to know too much about how it's done. Roach gets a guided tour of the "body farm" at the University of Tennessee, where cadavers are set out to rot, and forensic scientists study them in varying states of putrefaction to learn how to determine the time of death. Near the end of the visit she learns that, after three weeks, a body's internal organs resemble chicken soup. "So," says her guide in all seriousness, "lunch?"

Bartolome l'Anglais, *Dissection of a Cadaver,* fifteenth century

At a military medical research lab, other grisly scenes unfold: cadavers are dangled, marionette-like, over armed land mines to test the effectiveness of protective shoes. If the corpses were blocks of gelatin rather than formerly living muscle and blood, no one would give it a second thought. Roach, in fact, also witnesses ersatz thighs (made of gelatin) being shot full of holes to determine the stopping power of bullets, and learns that a "tweaked version of Knox dessert gelatin" is a good substitute for human flesh, though not vice versa.

A dense Latin title, something like *De cadaveribus male olentibus,* ("on foul-smelling dead bodies"), for instance, might have suited Roach's book better. She crams it with stories from so many sources that it resembles a medieval traveler's tale, indiscriminately conflating fact and rumor. To her credit, though, Roach has tracked many a weird tale to its source. She interviews the neurosurgeon Robert White, for instance, who experimented with keeping the isolated brains of dogs and monkeys alive inside other animals by hooking them up to the circulatory system. (The idea, as I understand it, is that people with terminal illnesses might have their heads swapped with those of brain-dead patients—effectively providing a whole-body transplant to needy multimillionaires.) She travels to Sweden to visit a company that markets a high-tech body composter as an alternative to crematoriums. (I imagined dinner at a friend's organic farm: "My late husband's in the tomatoes and the spinach. I hope you find him tasty.")

And in one of the most hilarious scenes in the book, the intrepid investigator flies to the Chinese island of Hainan to verify a 1991 Reuters article. Two brothers, according to the wire service, had been caught stealing the buttocks and thighs of cadavers awaiting cremation and turning them into "Sichuan-style dumplings," a popular mainstay of the local White Temple Restaurant. Roach later discovers that the whole story is a hoax—neither the brothers nor the restaurant exists—but not before she

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confronts the six-foot-tall director of a local crematorium, where one of the brothers allegedly worked, and is treated to a ten-minute harangue.

That some of Roach's stories are the stuff of urban legend comes as no surprise. That many of them are true, however, is what makes the guilty pleasure of reading her "book of the dead" so worthwhile.

The Great Wave: Gilded Age Misfits, Japanese Eccentrics, and the Opening of Old Japan
by Christopher Benfey
Random House, 2003; $25.95

Many of my college friends spent the early 1960s dreaming of smoke-filled San Francisco cafes where poets such as Lawrence Ferlinghetti, Allen Ginsberg, and Gary Snyder would intone the deep wisdom of the Orient. Snyder, perhaps because he had disappeared from the scene for a while, was the most alluring. After a prolonged Zen pilgrimage to Japan, he had returned with epigrammatic mantras extolling nature and the quest for unity with the cosmos. It was exhilarating to feel that our Western culture, its soul having been wasted by industrialization, was at last discovering the liberating philosophy of the East.

But in fact, that discovery had been made a century earlier. In the years following the "opening" of Japan by Commodore Matthew Perry in the 1850s, a group of intellectuals centered in New England had turned to Japan as a source of spiritual renewal. They viewed the austere aestheticism of Japanese culture as an antidote to the decorative excess of the Victorian era, and as a palliative for the spiritual agony of the Civil War. Ironically, at that same moment Japan was opening its doors to the West and, driven by an impulse toward modernization, moving away from the ceremonial formalism of feudal society. The Old Japan of the samurai and the Zen master was disappearing just as the West was coming to know it.

Christopher Benfey, a professor of English at Mount Holyoke College, has written a series of perceptive biographical essays that illustrate what happens when two such literate and disparate cultures begin to intermix. His opening essay cleverly contrasts the careers of the Japanese intellectual John Manjiro and the American author Herman Melville. Manjiro was adopted in the 1840s by a New England sea captain, who rescued him from a Pacific island after a shipwreck. He eventually returned to Japan, where he became one of the principal agents of modernization; he served as a go-between when Perry visited Yokohama, translated a seminal work on navigation from English into Japanese, and introduced such Western innovations as photography and telegraphy to the islands.

Melville, who crossed the Pacific in the other direction at almost the same time, never knew Manjiro, though they had acquaintances in Honolulu in common. Unlike Manjiro, who interpreted the material ingenuity of the West as a way to a better life, Melville was searching for moral renewal, and he associated that quest with the mysterious culture of Japan. The climactic scenes in *Moby Dick,* set near the Japanese coast, epitomized the yearning of the famous author and his contemporaries for what he described as "unknown Archipelagoes, and impenetrable Japans."

Yoshitoshi Tsukioku, *Commodore Perry arrives in Japan 7/8/1853*, c.1880

The cultural dichotomy is reflected in the lives of the remarkable figures who appear in Benfey's book: Henry Adams, chronicler of fin-de-siècle angst, was a pilgrim to the East; Percival Lowell, known today as the astronomer who thought Mars was inhabited, made his reputation by writing several books on life in out-of-the-way corners of Japan; Edward Sylvester Morse, who made the first archaeological digs in Japan, amassed immense collections that formed the core of museums on both sides of the Pacific; Isabella Gardner, Boston patron of the arts, had a love affair with the East that included Japanese intellectual Kakuzo Okakura, whose writings introduced Western socialites to the romance of the tea ceremony.

The dawn of the twentieth century, the point at which Benfey concludes his book, was of course only the beginning of cultural interchange between East and West. In the clean lines of Frank Lloyd Wright's houses, in the Japanese design of energy-efficient automobiles, and in the idealized orientalism of New Age culture, one can see elements of the same process

of cross-fertilization that began in the late 1800s. Benfey calls it "the great wave," an expression of the power and precariousness portrayed in Katsushika Hokusai's famous woodblock print. The ripples of that great wave are still coming ashore today.

The Seashell on the Mountaintop: A Story of Science, Sainthood, and the Humble Genius Who Discovered a New History of the Earth
by Alan Cutler
Dutton, 2003; $23.95

Nicolaus Steno died in 1686, at the age of forty-eight, with scarcely a penny to his name. Ten years earlier, before abruptly renouncing the pleasures of the world to become a priest and a religious ascetic, he had been the darling of Florence's intellectual elite and was known far and wide as a gifted anatomist and a brilliantly perceptive naturalist. His worldly goods at the time of his death amounted to little more than a decrepit clerical wardrobe and a shelf of well-worn books, yet he left behind a legacy of the highest order: the key to reading the deep history of the Earth, written in sedimentary rocks.

Renaissance thinkers of Steno's generation had come to the reasoned conclusion that the story of the Earth had been correctly set down in Scripture, the only generally accepted source of information about the distant past. No less a thinker than Newton had devoted reams of paper to the biblical chronology, and, like most everyone, Newton took it for granted that the events recorded in the Bible, including Noah's flood, were literally true. By counting "begets" and "begats" after the joining of Adam with Eve, and then adding a week for the Creation, one could work back to the date of *fiat lux*. The details varied from Renaissance writer to Renaissance writer, but the conventional wisdom was that the Earth had been around for about five or six thousand years.

Steno, however, was never a conventional thinker. He noted that the remains of shells could be found on mountaintops far from the sea; even forty days and forty nights of rain could not have raised sea levels that high. He marveled at how closely fossil shells resembled the shells of living species, rejecting the suggestion that fossils were naturally occurring formations that grew spontaneously in the rocks themselves. During his travels across Europe, Steno developed the idea that an intelligible order lay beneath the apparent jumble of the landscape's diverse geological features. Renaissance painters had tended to idealize landscapes, regarding them as immutable backdrops to human history. Steno realized that, on the contrary, rocks themselves had a story to tell.

Shortly before he entered ecclesiastical life, Steno published a slender volume "concerning a solid body enclosed by process of nature within a solid," setting forth a methodology for reading geological history in rock layers. Fossils, he claimed, were the remains of once-living organisms, turned to stone inside layers of silt or

Fossilized mollusks

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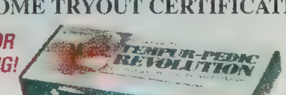

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and deposited by water. Subsequent events may have tilted or folded these layers, or eroded them over time, but they originally had been laid down horizontally, with the oldest layers at the bottom.

Such ideas, of course, are the fundamental principles of the sciences now called sedimentology and stratigraphy. By accepting Steno's principles, one had also to accept, by implication, a world millions or even billions of years old, for the mills of deposition—which can be observed in every river bottom and on every seashore—grind exceedingly slow. By mapping sediment layers and by noting similar strata, bearing similar fossils, one could put together a time line of geological history, chronicling the changing populations of plants and animals and the corresponding alterations in topography. Steno's insight, in short, implied a profound revolution in science, so it is notable that, though many books deal with the astronomical revolution of Copernicus, Kepler, and Galileo, Alan Cutler's short book is the first popular English-language treatment of Steno's life.

Steno died piously, fighting, through his example, what he considered a venal Catholic church bureaucracy. The great polymath Gottfried Wilhelm Leibniz, one of Steno's ardent admirers, lamented that "from being a great physicist he became a mediocre theologian." But Steno's scientific life, though tragically short, inspired many other pioneering students of the Earth's history: not only Leibniz but James Hutton, Charles Lyell, and, eventually, Darwin. Cutler's smart and readable biography puts Steno right at the forefront of the geological revolution. Clearly, he had joined the pantheon of science long before the church beatified him in 1988, officially setting him on the road to sainthood.

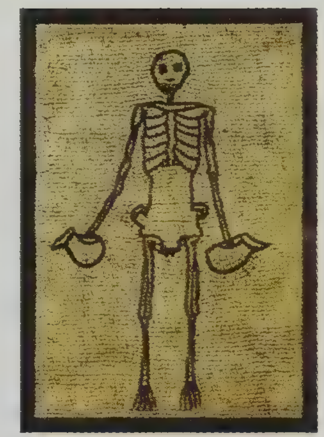
Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces software for education in astronomy.*

nature.net

SARS

By Robert Anderson

On February 11 authorities in China's Guangdong Province issued their first report of what they called an "atypical pneumonia." A global network of scientists began urgently exchanging news and findings via the Internet. Just two months later, they had positively identified the virus that causes severe acute respiratory syndrome (SARS). And, more remarkably, in those same few weeks two separate teams had sequenced its genome—all of its approximately 30,000 nucleotides. What made it all possible was the Internet. To learn how investigators responded so rapidly, visit the World Health Organization's Web page (www.who.int/en) and click on the "SARS" box. Under "For More Information," click on "WHO Collaborative Networks," and follow the Web trail there.



Memento Mori, Roman, fifth century

The SARS bug is a member of a group known as the coronaviruses, one or more of which are responsible for some common colds. At a site provided by the Centers for Disease Control and Prevention (www.cdc.gov/ncidod/sars/) you can consult the page choices on the left for both general and practical information about SARS—everything from "What Everyone Should Know" to travel advisories and fact sheets on quarantines.

To find out what the enemy looks like, go to www.rkm.com.au/VIRUS/CORONAVIRUS/index.html. In the artist's image of a single virion, you can see the "crown" of clublike projections for which the group of viruses was named. Click on any one of the drawings on the main page and scroll down: the illustrations are accompanied by information about viral replication and disease transmission, and there are also links to other sites. At the link "Coronaviruses and SARS," for example, Alan Cann, a virologist at the University of Leicester in England, has synthesized what is known about the disease to date. Cann's site is a good place to look for up-to-date, though fairly technical, information on infectious diseases in general. (You can access the site directly at www-micro.msb.le.ac.uk/3035/coronaviruses.html.)

Other viruses, many quite beautiful to look at, are depicted and described at the "Big Picture Book of Viruses" (virology.net/Big_Virology/BVHomePage.html), and at the University of Wisconsin-Madison's Institute for Molecular Virology (virology.wisc.edu/IMV/).

Finally, in a short article posted by the University of California at Los Angeles (www.college.ucla.edu/webproject/micro12/m12webnotes/viralevolution.htm), you can learn about viral evolution and its role in the epidemics of the past century. Some, like the influenza virus, are occasionally transmitted to people via contact with birds or other animals harboring new strains. That, incidentally, may well be the transmission path of the SARS virus.

Robert Anderson is a freelance science writer living in Los Angeles.

Ironing Out the Solar System

A long-extinct radioactive species sheds light on Earth's origins.

By Charles Liu

Our Sun formed a little more than four and a half billion years ago. Like every other star in the universe, it was born swaddled in a cloud of gas made almost entirely of hydrogen and helium. But the scattered debris of exploded stars—a fine cosmic dust made of heavier elements including carbon, oxygen, aluminum, calcium, and iron—was also sprinkled throughout the cloud. Those dust particles, far smaller than the ones that gather on a windowsill, served as collection points in the solar nebula: other matter, including ice and frozen carbon dioxide, aggregated around them. And so the aggregates grew larger, becoming pebble-size, then rock-size, then boulder-size masses.

Moving the Ahnighito ("Tent") meteorite into the American Museum of Natural History, August 14, 1907. This meteorite and others provide important data on the early history of the solar system.

Within a few million years, trillions upon trillions of icy, stony, or metallic bodies swarmed around our infant Sun. During the next quarter-billion years, many of those objects continued to coalesce, forming the major planets, moons, asteroids, and Kuiper Belt objects [*see my column "Tightening Our Kuiper Belt," February 2003*]. Smaller objects are still out there orbiting the Sun, scarcely changed since their formation so long ago.

Occasionally, one of those leftover chunks of protoplanetary matter strikes Earth's surface. When it does, it becomes a meteorite. Souvenir collectors prize meteorites for their novelty, but we astronomers value them for their history. Such bodies record the story of the early solar system, the same way plant and animal fossils record the story of life on Earth. Sometimes it's possible to use them to examine the origin of the solar system itself. A new study conducted by Shogo Tachibana and Gary Huss at Arizona State University in Tempe does just that; by looking for radioactive iron—or, rather, its ghosts—in two of the oldest known meteorites, they've taken an important step toward identifying the event that triggered the birth of the Sun.

Iron on Earth isn't radioactive—at least not anymore. More than 90 percent of the iron atoms in everyday life, whether in buildings, brussels sprouts, or blood, contain twenty-six protons and thirty neutrons. Such atoms are known as iron-56. The remaining atoms contain either twenty-eight, thirty-one, or thirty-two neutrons. The varieties, or isotopes, of an element are diagnosed by the number of neutrons in their nuclei, but are named by adding the numbers of neutrons and protons together: thus, iron-56, iron-58, and so on.

Those four iron isotopes are all radioactively stable. Other isotopes of iron can exist, but they aren't stable. With time, atoms that make up the unstable isotopes spontaneously eject subatomic particles from their nuclei. That process (known as nuclear decay) changes the number of protons or neutrons in the nuclei, giving rise to other isotopes, or even to other elements. Eventually any given supply of an unstable isotope disappears.

The rate of such radioactive decay can serve as a clock for pinpointing important dates in the history of the Earth and the solar system. Measuring the ratio of a particular radioactive isotope to its stable decay products in some object makes it possible, at least in principle, to deduce how much time has passed since the object was last enriched with that particular radioactive species.

Because each radioactive isotope decays at its own constant rate, the decay rate can be expressed as a half-life, which is defined as the amount of time it takes for half of a sample of the isotope to decay. Measurements of short-lived isotopes such as carbon-14, whose half-life is about 5,700 years, can date archaeological finds from early human cultures; measurements of longer-lived isotopes such as uranium-238, with a half-life of

nearly 4.5 billion years, can date the formation of rocks, planets, and stars.

Iron-60, a radioactive isotope with a half-life of just under 1.5 million years, can be readily produced only by high-mass stars just before they self-destruct in supernova explosions. That unique origin is a useful property when it comes to reconstructing cosmic events. If there was any iron-60 in the original solar nebula, it was probably all there right off the bat, inherited from the molecular cloud that gave birth to the Sun. That gives a solid starting point from which to calibrate any aging processes that the clocklike decay of iron-60 can measure.

Tachibana and Huss examined the isotopic composition of about a dozen small samples from two ancient meteorites. The two objects, called Bishunpur and Krymka after the places where they were discovered (in India and Ukraine, respectively), are chondrites—a class of objects that formed within a few million years of the Sun's birth. Any iron-60 that was incorporated into the two chondrites is long gone; it all decayed into radioactive cobalt-60, which in turn decayed into a stable atom, nickel-60.

Examining microscopic mineral grains embedded in the meteorites, Tachibana and Huss measured a significant excess of nickel-60, indicating that iron-60 was once present. Using other elements and isotopes as reference clocks, they then backtracked through the decay history of iron-60 and found that the solar nebula was originally made up of about 300 atoms of iron-60 for every billion (10^9) atoms of stable iron-56. That might seem like a minuscule figure, but it's ten times the typical ratio present in the interstellar gas of our Milky Way galaxy today. And that additional iron-60 in the early solar system speaks volumes about our cosmic origins.

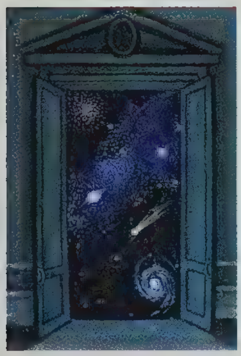
Astronomers know that the Sun was created in an interstellar gas cloud. We also know that something happened to induce part of that cloud to reach a critically dense state, which caused it to collapse inward and eventually to form the solar nebula. What was that triggering event?

A model proposed long ago suggests that the blast wave of a supernova was the culprit. The concentration of iron-60 in the two ancient meteorites lends new support to this idea. The expanding shell of stellar material, infused with iron-60 from the supernova explosion, may have seeded the presolar nebula with this radioactive-iron clock. At the same time, it would have provided just the kick needed to begin the formation of the Sun, the solar system, and, ultimately, the Earth.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN JUNE

By Joe Rao



Mercury reaches its greatest western elongation on the 3rd—24 degrees from the Sun on the dome of the sky—but skywatchers will still have to struggle to glimpse the reticent planet. In the first three weeks of the month, Mercury scarcely surmounts the east-northeastern horizon at mid-twilight. With good binoculars you might detect it as sunrise draws near; nearby Venus can serve as a guide. Early in the month Mercury shines just 4 degrees to the right of Venus and draws to within half a degree by the 21st, to Venus's lower right. A few days thereafter, Mercury disappears into the dawn glow.

Venus rises an hour before sunrise for yet one more month. You'll find it very low, just above the east-northeastern horizon, about twenty to thirty minutes later.

Mars rises at about 1 A.M. local daylight time at the start of June and before midnight by month's end. Look for it above the east-southeastern horizon. Mars outshines every other starlike object except its consort, Venus. As the distance between Mars and Earth decreases from 71 million miles to 53 million miles during June, the planet's apparent brightness doubles, from magnitude –0.7 to –1.4.

Even though Jupiter is on the far side of the Sun and about as small as it ever appears, it is still the brightest evening "star," and in a telescope it still shows the largest disk of any planet. It sets progressively earlier all month long: at about 12:30 A.M. at the start of June, and about 10:45 P.M. by the end. On the 4th, Jupiter shines to the right of the waxing crescent Moon.

Saturn may be visible during the first week of June. On the 1st it sets less than ninety minutes after the Sun. As darkness falls, the planet hovers below and to the left of the slender sliver of a crescent Moon, close to the west-northwestern horizon. A week or so later, Saturn disappears into the evening twilight glow; it reaches conjunction with the Sun on the 24th.

The Moon waxes to first quarter on the 7th at 4:28 P.M., and waxes full on the 14th at 7:16 A.M. It wanes to last quarter on the 21st at 10:45 A.M., and cycles back to new on the 29th at 2:39 P.M.

The solstice takes place on the 21st at 3:10 P.M. Summer begins in the Northern Hemisphere, and winter in the Southern.

Unless otherwise noted, all times are given in Eastern Daylight Time.

The Lure of Chocolate

Sweet chocolate candy is a rather recent invention. It made its debut in 1847.

Chocolate has enchanted humanity for centuries with its tempting taste. The Maya had a glyph for it and at one time there were nearly 2,000 chocolate cafés in London alone. Now here is a chance to look at the science behind the seduction. Starting June 14, the American Museum of Natural History will feature *Chocolate*, an exhibition devoted to the ecology, anthropology, history, and economics of this treat. The exhibition will be on view in Gallery 3 through September 7, 2003.

Chocolate begins by luring visitors into a tropical rain forest where they can examine a replica of a *Theobroma cacao* tree, which produces the seeds that are used to make the sublime substance. This section explores the complex ecosystem that supports the tree, the insects that pollinate it, and the birds that nest in its limbs.

The exhibition goes on to consider the role of chocolate in the lives of ancient indigenous civilizations. On view will be carved vessels, cacao seeds in dishes, and chemical residues in pots that helped scientists trace the roots of chocolate to the ancient Maya, the first to turn the bitter seeds of the cacao into a spicy beverage used in ceremonies and trade. An interactive Aztec marketplace will demonstrate the power of chocolate—its use as a luxury libation for the elite, an offering to the gods, payment to rulers, and money in the market. Visitors will also find out what treasures Cortés discovered in Montezuma's storerooms.

CHOCOLATE
June 14–September 7
Gallery 3

The sections that follow document chocolate's extensive reach, beginning with the Spanish conquest of the Americas and the ensuing European quest for cacao. Exhibits will illustrate that while wealthy consumers frequented the most elite chocolate houses in Europe during the 17th, 18th, and 19th centuries, thousands of slaves toiled on sugar and cacao plantations to keep up with demand. Visitors will also learn about the important role chocolate manufacturing played in the industrial revolution and the fascinating relationships among growing, selling, and consuming cacao in the modern global market.

Chocolate concludes with the cacao bean's role in the world today. Visitors will learn how it is harvested and prepared; what farmers are doing to earn an income while preserving the rain forest; the role of chocolate in different world cultures; and the myths and realities of chocolate's effect on health.

Chocolate *and its national tour were developed by The Field Museum, Chicago. This project was supported, in part, by the National Science Foundation.*

Art(ifacts) and Science of Chocolate

Ten celebrated chocolatiers and pastry chefs have been invited to sculpt signature pieces in chocolate inspired by the Museum's collections. Several of the pieces will be on exhibit at the Museum in early June and the remaining pieces will be unveiled on July 17 when, at 7:00 p.m., some of the participants will gather to discuss the creation of their pieces. Robert Wolke, professor of chemistry and a syndicated columnist for *The Washington Post,* will discuss the chemical and physical processes that enable chocolate to be molded into art. Don't miss this fun and fascinating event! For more information, call 212-769-5200.

Chocolate for this project has been donated by Felchlin, Valrhona, the Guittard Chocolate Company, and Dairyland.

CONFERENCE

The Science of Chocolate: Recent Discoveries

Tuesday, 6/17, 1:00–5:00 p.m.

Botanists, archaeologists, and chemists come together to discuss the cutting edge of research into chocolate. Scientists will consider the ritual uses of chocolate among the Maya, the recent discovery of the oldest-known chocolate, the medicinal qualities of the substance, and more.

LECTURE

Can Chocolate Save the Rain Forest?

Tuesday, 6/17, 7:00–9:00 p.m.

Chris Bright and Radhika Sarin of the World Watch Institute discuss the future of "forest-friendly" chocolate agriculture in Brazil and the Ivory Coast with Meg Domroese of the Museum's Center for Biodiversity and Conservation.

FAMILY PROGRAM

The ABCs of Chocolate

Saturday, 6/28, 2:00–3:30 p.m.
(Ages 7 and up, each child with one adult)

Discover the delectable world of fine chocolate in this hands-on experience. Learn how cacao is grown and processed, and roll your own chocolate truffle. *Not recommended for children with food allergies.*

ADULT WORKSHOP

Chocolate Appreciation

Sunday, 6/29, 11:00 a.m.–12:30 p.m., or 2:00–3:30 p.m.

In this intensive class designed for beginners as well as those with more experienced palates, renowned pastry chef Steve Klc will teach you how to recognize the characteristics of fine chocolate and how to shop for it.

Chocolate Tastings

CHOCOLATE SHOP, THIRD FLOOR

Most weekends during the run of the exhibition *Chocolate*, you can sample fine chocolate in the retail shop outside the exhibition. Chocolatiers will be on hand to discuss the characteristics of their distinctive products and the luxurious treats will be available for purchase. Visit www.amnh.org or call 212-769-5100 for the complete schedule of tastings, book signings, and other events.

A cacao tree on an organic farm in Bahia, Brazil.

MUSEUM EVENTS

EXHIBITIONS

Vietnam: Journeys of Body, Mind & Spirit
Through January 4, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.


C. CHESEK/AMNH

A life-sized votive horse made of paper and bamboo.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the ***Freeman Foundation****. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

Discovering Vietnam's Biodiversity
Through January 4, 2004
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

Einstein
Through July 27, 2003
Gallery 4, fourth floor
This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

ADULT WORKSHOPS

Genomics Laboratory Workshops
Tuesday, 6/10, 7:00–9:00 p.m.,
or Tuesday, 6/17, 7:00–9:00 p.m.
An introduction to genomics, followed by isolating and sequencing your own DNA.


CRYPTOGAMIC BOTANY COMPANY, 2003

Ulva lactuca, pressed seaweed specimen

The Artistry of Algae
Saturday, 6/28, 10:00 a.m.–5:00 p.m., and Sunday, 6/29, 1:00–5:00 p.m.
This two-day workshop combines science and art. With Alex Frost, Director of the Cryptogamic Botany Company.

SUNSET CRUISES

Sunset Cruise up the Hudson River
Tuesday, 6/10, 6:00–9:00 p.m.
Survey the geological features of the river and the Palisades, and learn about the environmental concerns facing this important waterway today.

The Nooks and Crannies of Eastern New York Harbor
Tuesday, 6/17, 6:00–9:00 p.m.
Follow the East River into Newtown Creek and then head to the Brooklyn Navy Yard, the South Street Seaport, and Buttermilk Channel.

FAMILY PROGRAM

The Underwater World of Sampson the Frogfish
Saturday, 6/14, 2:00 p.m.
Close-up 3-D photography brings to life the beautiful world of coral reef habitats.

CHILDREN'S WORKSHOPS

Drawing and Painting African Mammals
Sunday, 6/8, 10:30 a.m.–1:30 p.m.
(Ages 9 and 10)

Yikes! Your Body Up Close
Sunday, 6/8, 10:30 a.m.–1:30 p.m.
(Ages 7 and 8)

Experience the sights and sounds of a bustling

Vietnamese Marketplace

and sample traditional foods at Café Pho.
Through January 4, 2004

77TH STREET LOBBY, FIRST FLOOR

Fly Me to the Moon
Saturday, 6/14, 12:00–1:30 p.m., or 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Dinosaur Expedition
Sunday, 6/15, 10:30 a.m.–1:30 p.m.
(Ages 9 and 10)

Crime Lab Investigation
Sunday, 6/22, 10:30 a.m.–1:30 p.m.
(Ages 8 and 9)

The Sun and Its Energy: A Summer Solstice Celebration
Sunday, 6/22
12:00–1:30 p.m. (Ages 7–9)
2:30–4:00 p.m. (Ages 10–12)

Astronomy across Cultures
Tuesday–Thursday, 6/24–26, 2:00–3:30 p.m.
(Ages 10–12)

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe: The Solar Neighborhood
Tuesday, 6/3, 6:30–7:30 p.m.

Celestial Highlights: Carnivores in the Sky
Tuesday, 6/24, 6:30–7:30 p.m.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford

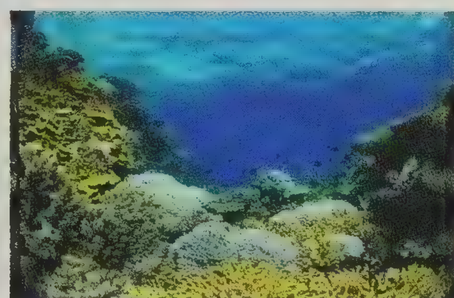
Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

LARGE-FORMAT FILMS

In the Samuel J. and Ethel LeFrak IMAX® Theater

Coral Reef Adventure
A fantastic underwater journey to document some of the world's largest and most beautiful—and most threatened—reefs.


©MACGILLIVRAY FREEMAN FILMS

Scene from *Coral Reef Adventure*

Pulse: a STOMP Odyssey
Take a rhythmic voyage of discovery around the world of percussion and movement.

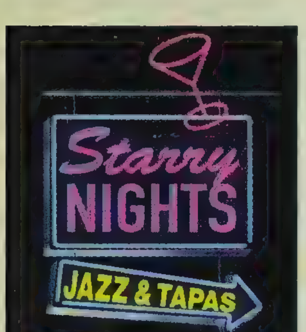
INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.



Starry Nights: Live Jazz

Friday, 6/6, 5:30 and 7:00 p.m.
Rose Center for Earth and Space
David Sánchez
This performance will be broadcast live on WBGO Jazz 88.3 FM.

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan and WNBC-TV.

Museum Shop to Carry Mikimoto Pearls

In celebration of the opening of the Irma and Paul Milstein Family Hall of Ocean Life, the Museum Shop is proud to introduce Mikimoto pearls as part of its collection of fine jewelry. Mikimoto is considered the world's finest brand of pearls and is available exclusively at top jewelers. The Museum is proud to be one of the select retailers to carry this fine brand. Stop by the Museum Shop today to check out the Museum's Mikimoto collection.

Become a Member of the American Museum of Natural History

As a Museum Member you will be among the first to embark on new journeys to explore the natural world and the cultures of humanity. You'll enjoy:

- Unlimited free general admission to the Museum and special exhibitions, and discounts on the Space Shows and IMAX® films
- Discounts in the Museum Shop, restaurants, and on program tickets
- Free subscription to *Natural History* magazine and to *Rotunda*, our newsletter
- Invitations to Members-only special events, parties, and exhibition previews

For further information call 212-769-5606 or visit www.amnh.org.

ENDPAPER

Damsels Cause Distress

By Gwen Mergian

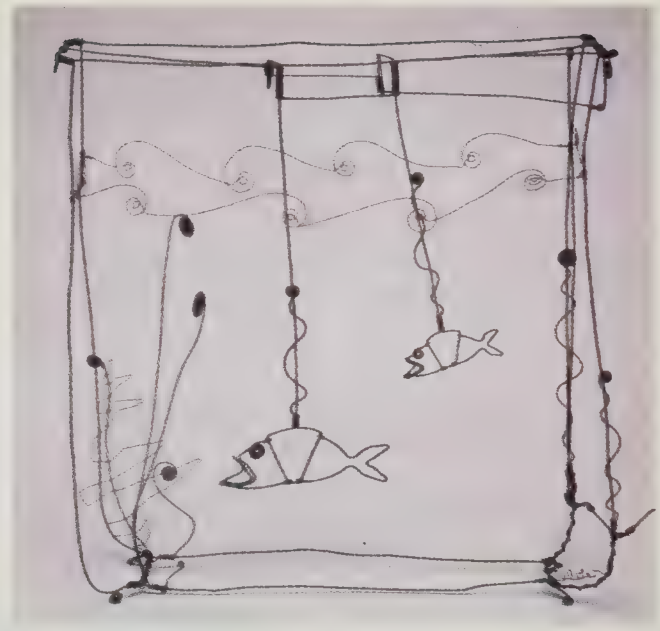
After waffling for years, my husband took the plunge and purchased a large saltwater aquarium for his office. That he did so while I was out of town at a conference may have shown a certain lack of confidence that I would react favorably, but he needn't have worried: I was hooked right from the start.

The tropical fish tank came fully equipped: pumps, filters, hoses, light fixtures, coral arrangements, and a small cadre of lively black-and-white-striped damselfish, also called demoiselles. These gals, however, were no ladies-in-waiting. Like many coral-reef species, damselfish are aggressive and highly competitive. As we soon discovered, even small fish can display some mighty big attitude.

Take our alpha female, a fish that quickly earned the name Tuffy. This one-inch wonder ruled every inch of the tank, demanding—and getting—the most food, the best hiding place, the last word in everything. What's more, the dominant demoiselle seemed to flaunt her power, chasing her underlings and pinning them into corners of the aquarium. Sometimes Tuffy kept them trapped for hours before allowing them to escape. As I watched these daily shenanigans, I was compelled to note the similarities between the world of fish and the world of business. I had run into quite a few Tuffys in my time.

Soon after the aquarium arrived, my husband decided to add two small snails to the system, hoping to control the growth of algae. When he popped them into the water, the pair went to work, slowly scouring the gravel at the bottom of the tank with their little antennae. "Ah, another fish-tank phenomenon to marvel at," I thought.

But Tuffy thought otherwise. Within minutes of the snails' arrival the hostilities commenced. Tuffy began the assault by dive-bombing the newcomers, swimming first to the top of the tank to gather momentum, then crashing straight into them at full force. The snails scattered under the fury of the attack. After a while, Tuffy adopted a second approach: she would pick up a snail with her mouth, swim to a patch of jagged rocks, hover over them, and drop the snail down on them. The merciless assault went on for hours and resumed the following day.



Alexander Calder, *Fish Bowl*, 1929

I hardly slept that night.

The next morning, I tiptoed up to the tank, only to discover a strange and curious sight. The two snails were anchored to the glass at the front of the aquarium and had formed a barrier that effectively blocked the only entrance to Tuffy's favorite retreat—a barnacle-like structure, centrally located, that she used as her personal palace. Tuffy dive-bombed the pair, trying to break their hold, but it was useless: the snails, one clinging to the top of the other, had wedged themselves perfectly between the barnacle and the glass. She tried to squeeze past them—first going forward, then sideways, finally backward. But the snails' adjoined, triangular shells held fast; there was simply no way for Tuffy to get past.

And the snails were in no great hurry to leave. They steadfastly maintained their position for three days. Only on the fourth day of the standoff did they finally move on, returning to the usual business of being snails. I breathed a sigh of relief: Is there anything that a few good friends, working together, cannot accomplish?

Life in the tank is calmer these days. Tuffy is still taunting her companions into daily acts of submission, but she mostly ignores the two snails. And the snails are quite content to roam around in their deliberate, gentle way. My husband is happy too, because he's got the algae growth under control at last. And Tuffy is back in her favorite place, peering out with satisfaction over her dominion.

Gwen Mergian and her saltwater friends live in upstate New York.

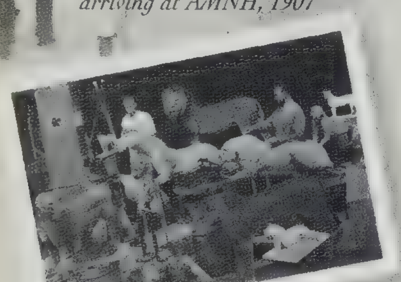
EXPLORER GUIDE

AMERICAN MUSEUM OF

All Photos: AMNH Archives

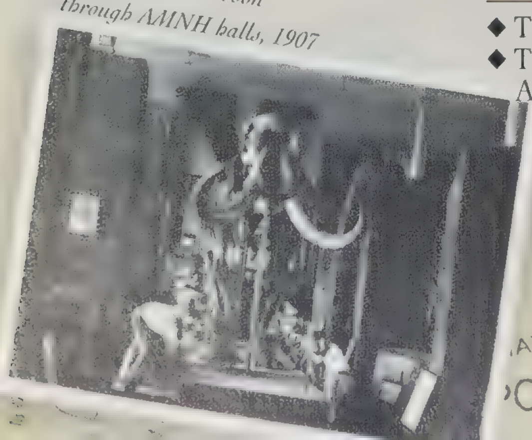
Assembly of Apatosaurus, unveiled at AMNH, 1905

Ahnighito meteorite arriving at AMNH, 1907



Using Akeley's taxidermy technique, 1934

Wheeling a mastodon through AMNH halls, 1907



2003

AUGUST

- The Legacy of Lewis & Clark August 20–30, 2003
- The Great Lakes Aboard *Le Levant* August 22–30, 2003
- Lemur Conservation: Tattersall's Madagascar August 24–September 8, 2003

SEPTEMBER

- North Pacific Odyssey: Aleutian Islands, Kamchatka Peninsula & Kuril Islands Aboard *Bremen* — September 2–19, 2003
- Conservation in Action: South Africa, Namibia & Botswana — September 2–20, 2003
- Daily Life in Morocco — September 6–20, 2003
- The Making of America Aboard *Clipper Adventurer* — September 7–21, 2003
- Swiss Alps to Budapest Aboard *Amadeus Classic* September 8–22, 2003

OCTOBER

- Village Life Along the Dalmatian Coast Aboard *Monet* — October 7–15, 2003
- AMNH in Patagonia — October 15–28, 2003
- Burma's Great Irrawaddy River Aboard *Pandaw 2* — October 16–November 1, 2003
- Polar Bear Watch on Canada's Hudson Bay October 17–22 & October 24–29, 2003
- Circumnavigating Sicily Aboard *Harmony G* October 25–November 3, 2003

2004

JANUARY

- The Galápagos Islands Aboard *Isabella II*
- Egypt Aboard *Sunboat II*
- Exploring Antarctica, the Falkland Islands & South Georgia Aboard *Peregrine Voyager*
- The Sea of Cortes: Baja Whale Watching Aboard *Spirit of Endeavour*

FEBRUARY

- New Zealand Aboard *Clipper Odyssey*
- Marine Ecology of Andros Island, Bahamas
- Astronomy & Volcanology Seminar in Hawaii
- Lands of the Maya Aboard *Nantucket Clipper*
- Thailand Cultural Festival
- The Kingdom of the Monarchs

MARCH

- The Amazon Aboard *La Amatista*
- Mysteries of Southeast Asia
- Family Costa Rica

APRIL

- The Great Markets of the World by Private Jet
- The Golden Age of Natural History: An AMNH & Oxford University Seminar
- The Food & Wine of Northern California Aboard *Yorktown Clipper*
- Safari Sketching Workshop in South Africa & Namibia

MAY

- Istanbul to Vienna Aboard *Amadeus Classic*
- Ireland & Scotland Aboard *Polar Star*
- Springtime in Japan Aboard *Clipper Odyssey*
- The Legacy of Buddhism in Tibet & Mongolia
- Southern Africa's Great Rail Journey
- Early Man: Lisbon to Bordeaux Aboard *Clipper Adventurer*
- D-Day Remembered: A Special Invitation fro[m] Smithsonian Institution

JUNE

- North Pole Aboard *Yamal*
- Montana by Rail
- Family China
- Ancient Rituals by Private Jet
- Archaeology of the Ancient Olympics: The Greek Isles Aboard *Harmony G*
- Alaska Aboard *Empress of the North*
- Iceland & Greenland Aboard *Peregrine Mariner*
- Artists of Russia's Golden Ring Aboard *Borodi[n]*
- Australian Outback by Private DC-3

NATURAL HISTORY

Osborn Expedition; Egypt, 1907

Fossilized dinosaur tracks; Texas, 1939

Programs

In the Wake of Moors & Mariners: Spain, Morocco & the Canary Islands Aboard *Sea Cloud* October 27–November 9, 2003

Festivals of India: Featuring the Pushkar Camel Fair & *Palace on Wheels* October 28–November 13, 2003

Bhutan: The Dragon Kingdom October 30–November 14, 2003

OVEMBER

Cuba: A World in Transition November 6–17, 2003

AMNH & The Center for Cuban Studie Presents The Living Arts of Cuba November 10–19, 2003

- Exploring the South Pacific Aboard *Clipper Odyssey* — November 13–28, 2003

DECEMBER

- Australia's Great Barrier Reef Aboard *Coral Princess II* — December 9–19, 2003
- Christmas in Quebec December 10–15, 2003
- Family Thailand December 19–30, 2003
- Tanzania: A Family Safari in the Serengeti December 19–31, 2003
- Rainforests, Reefs & Ruins: A Belize Family Adventure December 27, 2003–January 4, 2004

Jochelson Expedition; Siberia, 1901

Preview

- Kamchatka: The Natural History & Indigenous Peoples of Russia's Far East

ULY

- Family Galápagos Aboard *Santa Cruz*
- Family Canadian Rockies
- Slavic Pompei: Archeology of Ukraine
- The Wilds of Borneo: A Family Adventure
- Family Peru

AUGUST

- The Baltic Sea Aboard *Song of Flower*
- The Trans-Siberian Railway from Vladivostok to Ulaanbaatar
- Kilimanjaro: Trek to the Summit
- Trans-Canada by Rail

EPTEMBER

- China & the Yangtze River
- Elephant Conservation & the Great Serengeti Migration in Kenya
- Trekking in Bhutan
- The Chinese Path to Enlightenment: Philosophers, Monks, & Hermits

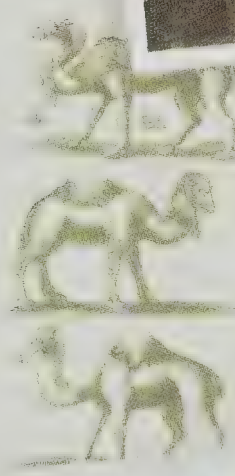
Delivering school collections, 1908

- Scotland Through the Ages
- The Great Lakes Aboard *Le Levant*
- Swiss Alps to Budapest Aboard *Amadeus Classic*
- Treasures from the Hills of Atapuerca
- Burma's Great Irrawaddy River Aboard *Pandaw 2*

Tangiers, Morocco, 1929

OCTOBER

- Festivals of India: Featuring the Pushkar Camel Fair & *Palace on Wheels*
- Over the Andes: Chile & Argentina
- Across Melanesia Aboard *Spirit of Oceanus*
- Margaret Mead's Papua New Guinea: Featuring *Melanesian Discoverer*
- Polar Bear Watch on Canada's Hudson Bay
- Greece to Sicily Aboard *Sea Cloud*
- The Ethnic Traditions & Biodiversity of Vietnam



NOVEMBER

- Casablanca to the Cape: West Africa by Private Plane
- The Archeology of Egypt & Jordan

DECEMBER

- Tanzania: A Family Safari in the Serengeti

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View of AMNH from Central Park

NATURAL HISTORY

7/03–8/03

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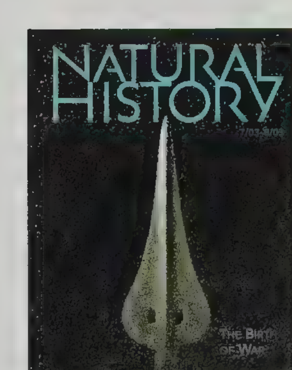
NATURAL HISTORY

JULY/AUGUST 2003 VOLUME 112 NUMBER 6

FEATURES



COVER

Spearhead from the Aegean island of Amorgos, Early Cycladic II, 2700–2300 B.C.

STORY BEGINS ON PAGE 28

Visit our Web site at www.nhmag.com

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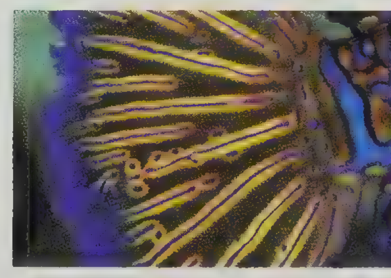

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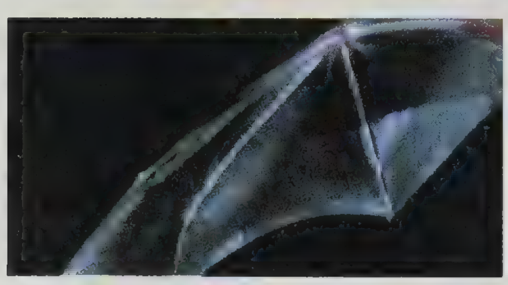

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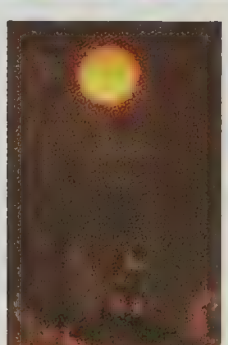

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How well do you really know your relatives?
Explore the mysteries of our living world with BBC Video.
BBC VIDEO
WALKING WITH CAVEMEN
The Life of Mammals
Hosted by David Attenborough
Available at amazon.com and you're done. or wherever DVDs & Videos are sold
BBC VIDEO

THE NATURAL MOMENT

Turf War

Photograph by Constantinos Petrinos

THE NATURAL MOMENT

See preceding pages

Staking out the boundaries of your spread can be a heedless act: In a Gary Larson cartoon a man points out a chirping sparrow to his son—emphasizing that territorial behavior occurs only among "lower" animals—while he stands amid a maze of picket fences in suburbia. But the male mandarin fish *(Synchiropus splendidus)* is anything but heedless about asserting its property rights. Every evening for about fifteen minutes the largest males—a whopping two inches long—among them the two fish pictured, fight their ongoing turf wars.

Alone by day, the psychedelically patterned mandarins graze on minute crustaceans—copepods—in the Indo-Pacific Ocean, hardly bothering to notice one another. But when the Sun begins to set, the focus turns to sex, and the large alpha males conspicuously secure a two- or three-square-foot plot of coral rubble for courting. Some nights, a harem of females joins a successful male that leads them one by one to the surface to spawn.

Photographer Constantinos Petrinos found a meeting site for mandarins in the Lembeh Strait, off the northern tip of the island of Sulawesi, Indonesia. He watched the alpha males seen here erect their spiky dorsal fins—a characteristic display of dominance—and was astonished when the mandarin on the left sank its teeth into its rival's neck. "They swirled for a few seconds," Petrinos reported, "until the loser fled to seek new territory."

—*Erin Espelie*

EDITOR'S NOTEBOOK

Tracks of War

After the disastrous looting of archaeological artifacts in Iraq, reported by our correspondent David Keys in our June issue, any positive news sounds virtually miraculous. So it was a relief to learn that many of the antiquities that had been on public display in Baghdad's National Museum had been hidden away by museum staff members before the war, sometimes in their own homes. Yet though some of the signature artifacts are safe, Keys still puts the number of stolen items in the thousands. Outside the Iraqi capital, where there are literally thousands of ancient sites, security remains patchy, and widespread looting, driven by the black market in antiquities, is continuing as we go to press.

For a broad perspective on warfare in this time of war, *Natural History* asked the anthropologist R. Brian Ferguson to describe his ongoing survey of the evidence for conflict at prehistoric archaeological sites around the world (see "The Birth of War," page 28). In a sense, his findings so far are encouraging: no unequivocal evidence of warfare appears at any site before sometime between 12,000 and 10,000 years ago—suggesting that war is by no means an inevitable feature of the human condition. Yet if warfare is a "recent" invention, its present near-universal reach makes it one of the most "successful" inventions ever made.

Seldom has scientific nomenclature been so aptly applied as in the botanical name for the genus of the cacao tree: *Theobroma,* "food of the gods" (see "The Chocolate Tree," by Robert A. Rice and Russell Greenberg, page 36). As an unrepentant chocoholic, I've accumulated enough T-shirts on chocolate themes to have a decent collection of the genre. My favorite is the "Will Rogers" version: on the front it says, "I never met a piece of chocolate I didn't like," and on the back it has a large hole made by the bite of what must have been a partly literate (but very confused) dog.

You won't find that shirt in the gift shop for the "Chocolate" exhibition, which just opened in New York City at the American Museum of Natural History. But you will see plenty of other offerings—and a lot of botanical and cultural artifacts on display as well.

• • •

Readers who don't want to miss a single one of Neil deGrasse Tyson's columns should not panic over this month's table of contents. Neil is taking a much-deserved vacation this month; his column "Universe" will return in the next (September) issue of *Natural History*.

—PETER BROWN

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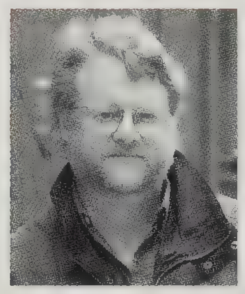
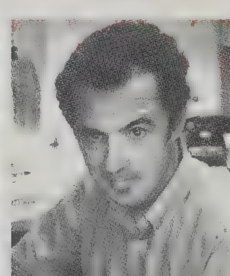
CONTRIBUTORS

Soon after graduating from Dartmouth College with an MBA, **Constantinos Petrinos** ("The Natural Moment," page 6) decided to trade in his business suits for diving gear. Based in Athens, Greece, Petrinos produced both text and photographs for the book *Realm of the Pygmy Seahorse: An Underwater Photography Adventure* (see www.petrinos.gr). His photograph of mandarin fish was particularly hard won, he says, because the fish were small, fast, and swimming among sharp coral.



Whether surveying the archaeological evidence of humanity's first armed conflicts, or evaluating biological theories about aggression in chimpanzees and in humans, **R. Brian Ferguson** ("The Birth of War," page 28) keeps one goal in mind: to help address current crises by expanding anthropological theory and linking it with other disciplines. A professor of anthropology at Rutgers University in Newark, New Jersey, Ferguson directs the Working Group on Political Violence, War and Peace at the university's Center for Global Change and Governance. He recently edited a collection of case studies of modern violence, *The State, Identity and Violence: Political Disintegration in the Post-Cold War World* (Routledge, 2002).

Robert A. Rice ("The Chocolate Tree," page 36) (far left) works predominantly on issues of tropical agriculture and land management. A geographer and policy researcher at the Smithsonian Migratory Bird Center in Washington, D.C., Rice helped organize the Smithsonian's first workshop on sustainable cacao production. His coauthor, the ornithologist **Russell Greenberg**, investigates the ecology of the migrant birds that winter in Latin America's human-dominated landscapes, such as coffee farms, cacao farms, and cattle pastures. Associated with the Smithsonian Institution for nearly thirty years, and director of the Smithsonian Migratory Bird Center since 1992, Greenberg helped launch conservation initiatives such as the Smithsonian's bird-friendly coffee program.



Since her early years as a graduate student at Duke University in Durham, North Carolina, evolutionary ecologist **Sara Lewis** ("Summer Flings" page 44) (near right) has been fascinated by fireflies. She is now an associate professor of biology at Tufts University in Medford, Massachusetts. In addition to inhaling countless mosquitoes while investigating firefly nuptial gifts, she and her colleagues study sexual selection in flour beetles and seahorses. Coauthor **James E. Lloyd,** perhaps the foremost expert on firefly taxonomy in the world, is a professor of entomology and nematology at the University of Florida in Gainesville. Lloyd, who has been investigating firefly ecology and behavior since 1962, is at work on a taxonomic monograph about *Photuris* fireflies, a genus whose deceptive signaling—the females rely on tricking other fireflies into becoming dinner—has provided much of the material for his work. In the guise of the "Firefly Doc," Lloyd is also the editor of *The Fireflyer Companion & Letter,* available at http://firefly.ifas.ufl.edu

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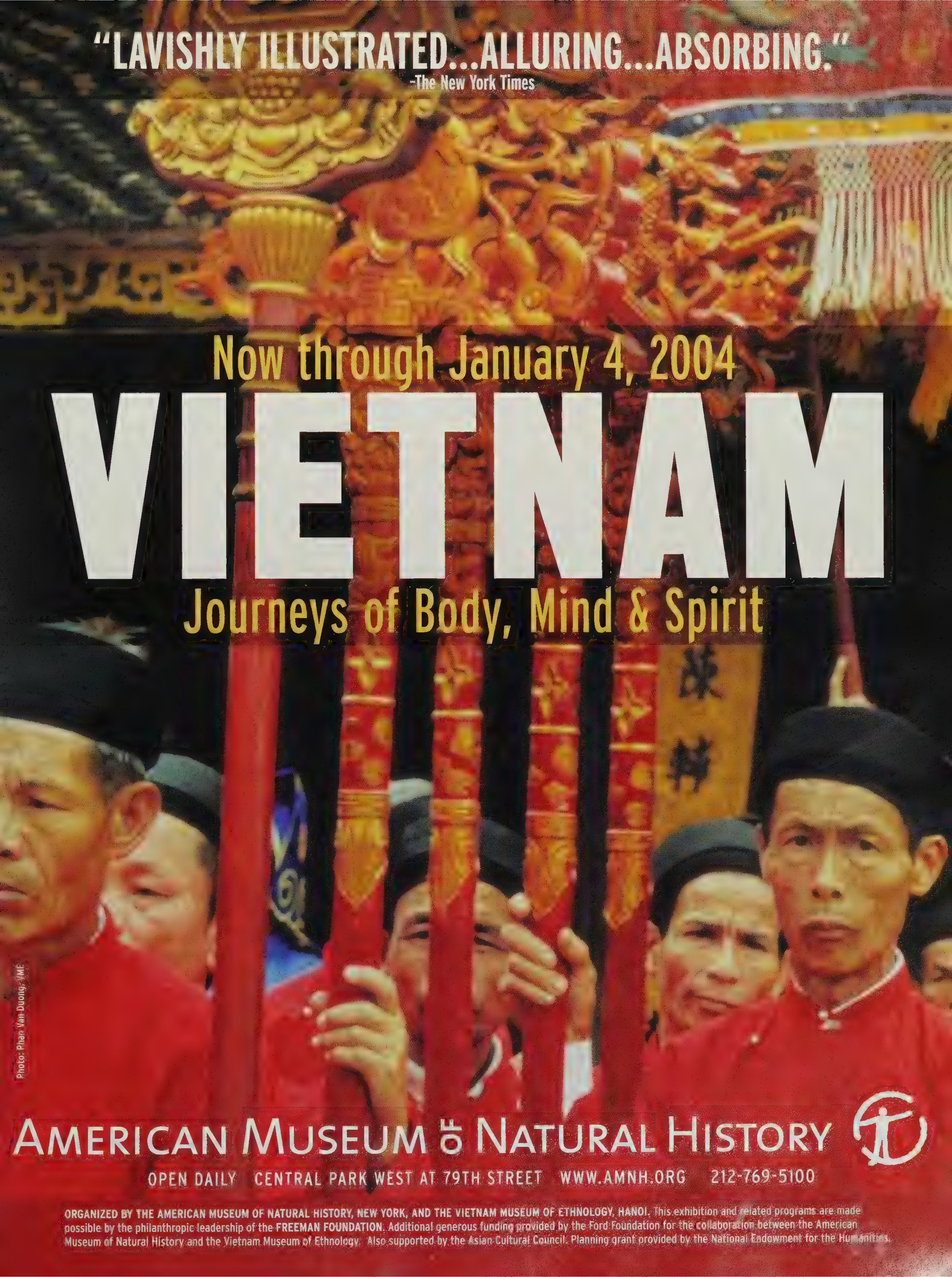
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Water for All

In her review of two books about Earth's supply of freshwater, Sandra Postel ["Hydro Dynamics," 5/03] writes of the need for a program that "fairly allocates the available water among all the parties." She speaks of a lasting Mideast peace depending on a "more equitable apportionment" of water between Israel and its neighbors; cites a UN convention calling for "equitable and reasonable use"; and warns that for most of the world's 261 rivers shared by two or more countries, "there is no treaty that divides the water equitably among all the parties."

But what is fair and equitable in the distribution of water? The same amount per capita, regardless of a country's total population? The same amount per country, regardless of the number of users? Should distribution be proportional to surface area, or should the country where the headwaters lie receive a greater share? Once set, should allocations stand for all time, or should they be renegotiated as population and other factors change?

John Tanton
Petoskey, Michigan

SANDRA POSTEL REPLIES: There is no magic formula for achieving an equitable apportionment of water among users of a shared river or aquifer. Many conditions must be factored into the calculations, such as climate, hydrology, population, existing and potential uses of the water, and the availability of alternative sources. It's up to all the parties involved (perhaps with help from an outside mediator) to hammer out a treaty that all will sign. Sometimes that may entail sharing the benefits of the river (irrigated crops, hydroelectric power) rather than fairly allocating the water per se.

Ideally, water treaties will be resilient. A good example is the treaty signed by India and Pakistan in 1960 to share the Indus River. The treaty took twelve years to negotiate (facilitated in the final nine years by Eugene R. Black, then president of the World Bank). But despite two subsequent wars and ongoing tensions between the signatories, the treaty has survived.

Too Close?

Although outstanding, Duncan Murrell's photograph of a feeding humpback whale in Alaskan waters ["The Natural Moment: Bubble Feast," 5/03] troubled me. The image and its accompanying text suggest it is acceptable to closely approach whales and other marine mammals. That is not the case.

The Marine Mammal Protection Act of 1972 requires those who "take" or "harass" marine mammals in U.S. waters to have a permit for doing so. The act treats commercial and educational photography as "level B harassment," and regulates it the same way it regulates research. Because humpback whales are an endangered species, additional regulations established in 2001 make it unlawful for anyone to come within less than 100 yards of these animals unless authorized to do so.

Jennifer Burns
University of Alaska
Anchorage, Alaska

DUNCAN MURRELL REPLIES: It is unfortunate that the law does not distinguish between low-impact kayaks and massive cruise ships, and that the whales are not conversant with the regulations and persist in approaching me closer than 100 yards. The encounter described was a freak incident, the result of the animal's approach without warning.

In my twenty years of kayaking in the presence of humpback whales in Alaska, I have never witnessed any perceivable change in their behavior patterns. That is in sharp contrast to the way I've seen them respond to motorized vessels—even if those boats remain outside the regulation distance and even if the people on board have research permits.

I stopped using boats with engines many years ago because I wanted to observe and photograph the whales for my educational work without disrupting their normal activities. (I do presentations for the Whale and Dolphin Conservation Society.) I think the sea would be a far better place for all creatures if more people followed this approach.

> *"In my twenty years of kayaking [with] humpback whales, . . . I have never [seen it lead to] any perceivable change in their behavior."* —DUNCAN MURRELL

Wondrous Strange

Adam Summers has cleared the air about a memorable encounter I've wondered about for decades ["Biomechanics: Serpents in the Air," 5/03]. Walking alone along a jungle path on the Philippine island of Bongao, I spotted, coming from the high green canopy, a snake gliding toward me. I felt more awe than fear, and quickly eluded the snake, which, upon landing, darted rapidly up a tree nearby, tongue flicking, seemingly ready to try again. Knowing I would not be believed, I told no one. Mr. Summers has at last assured me that the experience had a mechanical explanation.

Richard Sutherland
Metchosin, British Columbia

Magnificent Monitors

Adam Summers's essay on how monitor lizards can effectively breathe while running ("Biomechanics: Monitor Marathons," 6/03) could have discussed other unusual, but related, biologi-

cal features of these most advanced of all lizards. Many monitor lizards are top predators in their communities. They are more active and much more intelligent than other lizards, and their greater stamina enables them to search widely for food. Savannah monitors, living in Africa, range several miles a day in search of prey.

The exceedingly successful body plan of varanid lizards and their close relatives has been around at least since the days of a creature that lived in what is now Mongolia, 80 million years ago. Most monitors are larger than most other lizards. Indonesian Komodo dragons *(Varanus komodoensis)* attain lengths of ten feet or more and can weigh as much as 350 pounds. Komodo monitors, however, are themselves dwarfed by the closely related—though, unfortunately, now extinct—Australian monitor *Varanus priscus.* The latter species (formerly known as *Megalania prisca*) reached more than twenty feet long and weighed more than half a ton. Fossils of this giant are estimated at between 19,000 and 26,000 years old.

Varanid teeth are serrated along the rear edge, which helps the animals cut and tear the skin and flesh of their prey as they pull back on their bite. That is how *V. komodoensis* routinely kill deer and pigs; one Komodo monitor even eviscerated a water buffalo! With its slashing bite that could disembowel large mammals, *V. priscus* was the Australian ecological equivalent of the large saber-toothed cats that lived on other continents. People were probably among these monitors' victims; curiously, though, fierce, giant man-eating lizards don't appear in the Dreamtime stories of Australian Aborigines.

Eric R. Pianka
University of Texas
Austin, Texas

Small Farmers

Jessie Gunnard, Andrew Wier, and Lynn Margulis ["Mycological Maestros," 5/03], having discovered that some populations of the termite *Heterotermes tenuis* consume spores of the fungus *Delortia palmicola,* suggest the termite might be a "missing link" to the higher termites that farm *Termitomyces* as their sole food source.

But the behavior of *H. tenuis* is not unique: many nonfarming termite species feed on fungus-infested wood. Because *H. tenuis* (of the family Rhinotermitidae) is not a direct ancestor of the Macrotermitinae, the "incipient farming" in *H. tenuis* is analogous, rather than homologous, to the elaborate fungus farming in the Macrotermitinae (a possibility the authors themselves raise).

Moreover, a "missing link" position for the South American *H. tenuis* is at odds with the supposedly African origin of fungus farming in termites. Likewise, for the fungi a true "missing link" would have to be a fungus that is sometimes farmed by termites and is also closely related to *Termitomyces.* This is not the case: *D. palmicola* (of the phylum Ascomycota) is as distantly related to *Termitomyces* (of the phylum Basidiomycota) as human beings are to protozoa.

Duur K. Aanen
University of Copenhagen
Copenhagen, Denmark

By colonizing wood, fungi "precondition" it, making it palatable to lower termites. No surprise, then, if fungal parts can be found in the guts of those termites. But the Macrotermitinae—the Old World subfamily of higher termites that engage in rather advanced fungus growing—feed predominantly on dry or freshly

dead organic materials, which contain few fungi. The *Termitomyces* fungus farmed and ingested by those termites is therefore the first microorganism to attack the forage. Many species of Macrotermitinae degrade cellulose internally, with assistance from the fungus; in other species the fungus breaks down the plants' xylan and lignin.

The overall picture is one of an evolving diversity of mutualisms. Fungal nodules pass rapidly through the gut and germinate. Not enough are consumed to fully support the colony nutritionally; most termites feed on the fungus's more general fungal threads, which are richer in nitrogen than primary forage is. Thus the fungus is a composter, making energetically expensive nitrogen fixation unnecessary.

In spite of the complexity of the Macrotermitinae's mound constructions, the latest phylogenetic evidence places that subfamily in a basal position within higher termites, where the broadly dominant habit is the use of soil as a building material and/or as a food. We think the fungus found the termite and not vice versa.

David Bignell
University of London
London, England

Paul Eggleton
The Natural History Museum
London, England

After reading "Mycological Maestros," I finally know why the huge mushrooms I once (and only once) collected from a big termite mound in Zimbabwe are so rare: mushrooms appear only after the termite colony has abandoned the mound and stopped farming the fungus's mycelium. Those mushrooms, avidly sought by local residents, have a delicious, meatlike taste and texture strongly resembling that of the best commercial portobello mushrooms.

My own Zimbabwe research focused on the foraging habits of African elephants. I found strong ecological linkages between elephants and termites in woodland and savanna habitats in Africa: termites are the principal recyclers of elephant dung during the dry season.

Could cellulose-digesting protists live in the guts of elephants as well as termites?

Because both elephants and termites rely on microbial gut symbionts for digestion and nutrition, and because termites in Africa and Asia are intimately associated with elephant dung, it would be exceedingly interesting to determine whether any species of cellulose-digesting protists live not only in termites but also in the guts of elephants.

Joseph P. Dudley
The Pentagon
Washington, D.C.

LYNN MARGULIS REPLIES: Duur Aanen is correct. The behavior of the South American *H. tenuis* stimulates us to imagine the lives of the 200-million-year-old African ancestors of today's fungal gardeners.

David Bignell and Paul Eggleton assert that "the fungus found the termite and not vice versa." But whether the fungus found the termite or the termite discovered the fungus is scientifically indistinguishable. Wind-blown spores became delicious, fattening pinheads because of hungry insects. That's coevolution.

Joseph Dudley astutely suggests that elephants be examined for cellulose-digesting protists living in their guts. In fact, the search for cellulose-degrading microorganisms in elephants, as well as in beavers, pandas, and other mammals that feed on woody materials, promises rich rewards, particularly when the studies incorporate observations of the fossil record. With the electron microscope, my colleagues and I have observed, in 20-million-year-old Miocene amber, fragments of clearly identifiable plant xylem harboring protists and their adhering bacteria. We find termite muscle tissue, the cell nuclei and cell walls of wood, and even molecules of intestinal gas, such as methane and carbon dioxide. Similar success can be predicted with African elephant material.

AMENDMENTS: The letter by Maxwell Manes ["Letters," 5/03] concerning phi, the golden ratio, included a slip of the pen. The square of phi (not, as stated, phi) plus the reciprocal of phi is equal to two times phi.

Because of editing errors, two captions in last month's issue (6/03) made mistaken identifications. In "This Land: Ages of Aquarius," the plant shown in bloom in the bottom photograph on page 59 is mock orange *(Philadelphus lewisii)*. In "Peering at the Edge of Time," by Fulvio Melia, the caption on page 53 switched the identifications of the two constellations Scorpius and Sagittarius.

Natural History's e-mail address is nhmag@amnh.org

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By Stéphan Reebs

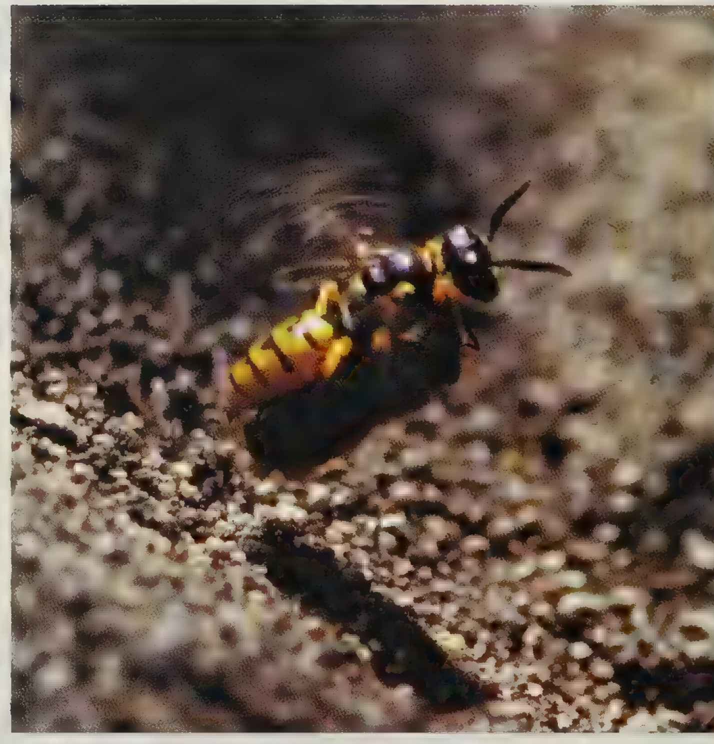
Little Engines That Could

It's hardly news that for many species, raising offspring takes a lot of energy. Add to that the wide variations among individuals, and you might well ask, What accounts for differences in energy, and do they affect reproductive success?

Consider an extreme case: the European beewolf, a species of wasp. To provision her young, the female stings and paralyzes honeybees that each weigh more than she does. Then she lofts the bees one at a time back to her nest-in-progress. During her lifetime a laid-back mama beewolf might hunt down five bees and lay five eggs, giving each of her offspring just one bee to see it through the larval stage. But a supermom might hunt four fat bees for each of as many as thirty-four eggs, more than twenty times the workload of her laid-back counterpart.

The biologists Erhard Strohm of the University of Würzburg and Wiltrud Daniels of the University of Bayreuth, both in Germany, decided that the beewolf was just the critter they needed to prove a direct connection between reproductive success and the ultimate source of animal energy: the mitochondria within every working cell. Specifically, they looked at the folded membranes on the insides of the mitochondria in the beewolves' flight muscles. Why? The denser the mitochondria's inner membranes, the faster the production of energy.

Strohm and Daniels orchestrated mating, breeding, and honeybee-hunting opportunities for a group of female beewolves. Each wasp was then killed, its weight and fat reserves (good determinants of reproductive success in other species) were measured, its age recorded, and the mitochondrial density and mitochondrial-membrane density of its flight muscles examined at high magnification.



Beewolf hauling dinner to her nest

The only factor that correlated with the beewolves' rate of bee killing was the membrane density. And the more bees a developing larva had to munch on, the more likely it was to survive. In beewolves, at least, being a supermom pays off. ("Ultrastructure meets reproductive success: Performance of a sphecid wasp is correlated with the fine structure of the flight-muscle mitochondria," *Proceedings of the Royal Society of London* B 270:749–54, April 7, 2003)

Ocean Dwellers of Avalon

Paleontologists once thought the shells and bones left by the organisms that emerged from the Cambrian explosion, some 545 million years ago, were remnants of Earth's earliest complex life-forms. But then fossils of earlier, soft-bodied creatures, now called Ediacarans, began to come to light. Recently the oldest such fossils in the world were discovered, on the Avalon peninsula at the southeastern tip of Newfoundland. Among them was a new species, *Charnia wardi.*

Twelve-inch segment of a fossilized Charnia wardi, *part of a six-foot-long specimen*

C. wardi grew to as much as six feet long but less than three inches wide, with slender, plantlike fronds branching off a midline. The organism was discovered, along with a less slender, equally ancient, and better-known cousin, *C. masoni,* in a rock formation 575 million years old. Guy M. Narbonne and James G. Gehling, both geologists at Queen's University in Kingston, Ontario, note that the creatures' fossil fronds lie parallel to one another, suggesting the *Charnia* were attached to the seafloor, and were reclining in a strong current before being covered by volcanic ash.

The fossils' age places them right on the heels—geologically speaking—of the last planetwide glaciation, 580 or so million years ago. Perhaps the aftermath of the freeze created the conditions for the rapid evolution of multicellular life [*see "The Longest Winter," by Gabrielle Walker, April 2003*]. Another possibility is that the Ediacarans evolved just before the glaciation and managed to live through it. ("Life after snowball: The oldest complex Ediacaran fossils," *Geology* 31:27–30, January 2003)

Experiment of the Month

Chances are that the birds breeding in your backyard this summer are the same individuals that did so last year. Some might have traveled thousands of miles to return to the red maple next to your rosebushes. But how could you prove your suspicion that the long-term memory of migrants is any better than that of nonmigrants?

Claudia Mettke-Hofmann and Eberhard Gwinner of the Max Planck Research Center for Ornithology in Andechs, Germany, had an idea. They hand-raised seventy-six garden warblers—a species that breeds in Europe and overwinters south of the Sahara—and fifty-five Sardinian warblers, a close relative that stays put around the Mediterranean. The investigators then gave all 131 birds two adjacent, identical-size rooms to explore for a few hours, one decorated with fake ivy, the other with fake geraniums. Only one room (sometimes the ivy room, sometimes the geranium room) contained food. On several subsequent occasions, the ornithologists offered groups of migrants and of nonmigrants the same choice of rooms—minus the food. Each bird was tested just once.

One month later the homebody Sardinian warblers showed no preference in rooms, presumably having forgotten where the benefits lay. But even a year after the initial exposure, the migratory garden warblers spent significantly more time in whichever room—ivy- or geranium-laden—had initially provided lunch. A migratory lifestyle thus seems to go hand in hand with a good memory. And that kind of memory might not be innate: the part of the brain that's crucial for processing environmental information is relatively larger in adult migrants than it is in untraveled juveniles. ("Long-term memory for a life on the move," *Proceedings of the National Academy of Sciences* 100:5863–66, May 13, 2003)

Computer simulation of a Neanderthal's thumb and index finger

Bones of Contention

In 1856 two quarrymen found an ancient cranium in the limestone-rich Neander Valley near Düsseldorf, Germany. Anthropologists have been arguing about Neanderthals ever since.

One controversy centers on the utility of the Neanderthal thumb. Well-preserved, 60,000- to 70,000-year-old remains from the La Ferrassie rock-shelter in south-central France show that Neanderthal thumb bones weren't proportioned like their modern counterparts. Hence some physical anthropologists have argued that Neanderthals couldn't grip tools securely—perhaps contributing to the species' extinction. But Wesley A. Niewoehner of California State University in San Bernardino disagrees.

Niewoehner and a team of colleagues made a computerized model of a crucial part of the hand by doing laser scans of epoxy casts of the thumb and index-finger bones of the adult male found at La Ferrassie. Then they conservatively estimated the bending and straightening capabilities of each joint. The digital data, along with the estimates, were then fed into the same animation program that created special effects for *The Lord of the Rings* and *Spider-Man*. The crucial test of manual dexterity was, Could the tip of the index finger be made to touch the tip of the thumb? Pressing "enter," the modelers watched the two Neanderthal digits on their computer screen slowly but surely form a fine A-OK sign.

Conclusion? The Neanderthals' demise couldn't have been caused by a physical inability to make and handle the tools of the time. Their hands worked much the same way as those of modern humans. ("Manual dexterity in Neanderthals," *Nature* **422**:395, March 27, 2003)

Up in Smoke

Grassland fires are often deliberately set by ranchers to remove dead, unwanted vegetation. Richard W.S. Fynn, a soil scientist at the University of Natal, and his colleagues can now reassure ranchers that for the most valued native grasses, regular annual burning doesn't have much of a downside.

Burning grassland, Royal Natal National Park, South Africa

A fifty-two-year study at a research farm in South Africa shows that burning leads to denser roots and more microbial activity, and springtime fires don't reduce the soil's organic carbon content. Burning does indeed deplete the topsoil of nitrogen, converting it to a gas, but native grasses don't need much soil nitrogen. And other studies at the same farm show no long-term reduction in the amount of grass produced. ("Burning causes long-term changes in soil organic matter content of a South African grassland," *Soil Biology and Biochemistry* 35:677–87, May 2003)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

Earth, Wind, and Fire

The fruit bats of Montserrat have had to contend with most of nature's torments.

By Scott C. Pedersen

It was July 1997, and a long night, which had followed a long day, was finally nearing its end. A volcano was grumbling, and rain had just begun . . . again. My right boot was quickly filling with water and sinking deeper into cold mud, and a large, muscular pig-nosed fruit bat *(Brachyphylla cavernarum)* had latched its mouth firmly onto the flesh of my thumb. I had been careless taking the bat out of one of my mist-nets—a finely spun net—and the bat was impressing this fact on me.

For once, though, the truth didn't hurt. Typically a bite from this species would have left me trying to stifle a string of colorful expletives, but this animal didn't have a tooth left in its head. The rather soggy-looking, unfortunate animal was also just about entirely bald. Things were getting a bit surreal: a hairless, toothless bat was gumming my thumb as I stood on the flanks of an active volcano; large, glowing rocks were rolling down the slope in my general direction; and now the mud was beginning to swallow my other boot. I suddenly felt the need for a very cold beer.

The pig-nosed fruit bat, Brachyphylla cavernarum

The pathetic bat and I were in the British crown colony of Montserrat, a rugged, forty-square-mile tropical island in the northern Lesser Antilles, some 250 miles southeast of Puerto Rico. Although Columbus never bothered to land on the island, he named it, in 1493, after a Spanish monastery near Barcelona, famous for its wooden statue of the Virgin and child. The British colonized the island in 1632, and a succession of sugar cane, cotton, and lime plantations dominated the local economy.

Montserrat lies in the middle of the Atlantic Ocean's "hurricane belt," a highway of sorts for the storms heading north from the Tropics. At least thirty hurricanes have battered Montserrat in the past 360 years; twelve have been severe, and Hurricane Hugo, in 1989, was the most destructive in recent history. Montserrat also lies near the convergence of the North American and Caribbean tectonic plates, so if the hurricanes don't get you, the earthquakes and volcanic eruptions might. Major temblors hit the island in three periods: 1898–1900, 1933–36, and 1966–67. Seismic activity in the Soufriere Hills volcano, beginning in 1992, resulted in an explosive eruption in July 1995, followed by a series of pyroclastic mudflows that destroyed and buried most of Plymouth, the island's capital, by 1998. Subsequent eruptions have reduced much of the southern half of the island to a wasteland. (Although the volcano's activity has decreased for

The Soufriere Hills volcano on Montserrat simmers with clouds of ash and steam. The volcano erupted explosively in July 1995, and subsequent eruptions have covered a large part of the island with hot ash and rock.

the moment, it is too soon to tell whether the current cycle of eruptions is at an end.)

It is hard to convey the scope of the human tragedy the recent eruptions have visited on this small island community. Casualty reports vary widely, but officially, at least twenty-one Montserratians were killed. Between 1997 and 1998, thousands were forced to emigrate, to neighboring islands, Canada, England, or the United States. Many families were separated, and a vibrant and unique culture was temporarily put on hold until the volcano settled down and the islanders could begin to rebuild the island's infrastructure.

In the midst of all this suffering, it might seem crass to worry about wildlife. But even before the eruption, Montserrat—a small but lush island—had been getting a great deal of attention from biologists interested in island biogeography. Bat biologists had been at work there since 1978; I arrived in 1993. Since our studies began, my coworkers and I have compiled a reasonably complete natural history of ten bat species (six fruit bats, three insectivores, and one carnivore that specializes in capturing small fish with its hind feet), covering the good times as well as the periods marred by the overlapping effects of devastating natural disasters.

Hurricane Hugo was the first such disaster under our watch; it smashed directly into Montserrat, careened into Puerto Rico, and eventually hit the eastern seaboard of the U.S. For the fruit bats on the two islands, survival in the aftermath of the storm was a matter of size—the islands' size. On Puerto Rico, fruit bat

The fishing bat, Noctilio leporinus, *swoops low over water, hunting with its feet. Volcanic eruptions destroyed the bat's only known habitat on Montserrat.*

populations could abandon hurricane-damaged forests and disperse across a larger landmass into unscathed areas. On Montserrat, Hugo was a crushing blow for tree-roosting and other highly specialized bat species; their numbers fell twentyfold. Many fruit bat populations suffered primarily because there was nowhere for them to go. Their roosts and food sources—much of the island's forests, really—had simply been blown out into the Caribbean.

Not all the island's bat populations crashed in Hugo's wake. A large colony of pig-nosed fruit bats roosts in a series of relatively hurricane-proof caves at the northern end of the island. The animal also enjoys a catholic menu of flowers, fruits, insects, leaves, nectar, and even immature legumes. Such omnivory proves to be a powerful survival strategy when disasters limit the availability of particular foods.

I fully expected to spend many years monitoring the post-Hugo recovery of Montserrat's bat populations, with a special focus on the cave-dwelling colony of pig-nosed fruit bats. The 1995 eruption of the Soufriere Hills volcano, however, dramatically redirected my research program.

Ash mixed with water became massive mudflows, which buried entire towns in Montserrat.

Hurricanes and volcanic activity differ fundamentally in both their immediate and long-term effects on ecosystems. The tremendous wind speeds of hurricanes typically strip foliage and most of the trees' fruit crop. Large hurricanes such as Hugo also strip bark from large trees and knock smaller trees over, destroying roost sites for tree-roosting species of bats.

Volcanoes are another matter. Explosive eruptions result in pyroclastic flows—landslides of superheated gas, rock, and clouds of volcanic ash that typically move faster than fifty miles an hour and reach temperatures of between 200 and 700 degrees Celsius. They incinerate, suffocate, or bury everything in their paths. Unconsolidated deposits of ash may eventually mix with water to become massive, quick-moving mudflows, called lahars, that can fill in small valleys. Lahars have buried entire towns and villages on Montserrat. Together, the

pyroclastic flows and the lahars have devastated the southern half of the island, burying many river drainages under tens of feet of sterile volcanic ash. On many parts of the island, ash smothered all vegetation; the weight of the ashfall stripped limbs from trees and toppled smaller plants, such as banana and heliconia. The destruction turned several of my old sample sites—once deep, lush valleys, replete with streams, pools, luxuriant vegetation, and huge trees—into nightmarish visions of the surface of the moon.

For example, large mudflows and a number of small pyroclastic flows from the Soufriere Hills volcano partially destroyed the Belham River and obliterated a quirky thirteen-hole golf course that had meandered across the river's bottomlands. Although the episode was clearly a setback for the Montserratian golfing community, the flows were catastrophic to a unique ecosystem that was also the island's only known habitat for the fishing bat *(Noctilio leporinus)*.

Fishing bats are large, yellow-orange, and rather pungent creatures that can hawk large flying insects or snag small ocean fish from the surf. But they much prefer to take minnows from the surface of freshwater streams and ponds—exactly what the course of the Belham River afforded. The fishing bats had survived Hugo as well as two years of volcanic eruptions. But with the loss of the river, they have not been seen on Montserrat since mid-1997.

Palates of two female pig-nosed fruit bats on Montserrat demonstrate the effect of volcanic ash on their teeth. The 1994 individual (far left) is healthy, but ash has worn away the enamel of the 1998 individual (near left). The wear exposes the underlying pulp cavity, which then becomes impacted with fruit. The acids in the fruit etch the rest of the tooth, causing abscess and, eventually, loss.

The pervasive destruction of foraging and roosting habitat across the southern portion of Montserrat forced the fruit bats (as well as the people) remaining on the island to relocate to its northern half. Predictably, the initial competition within the bat colony for limited food and shelter there was intense.

The survival struggles of Montserrat's large population of pig-nosed fruit bats became a lesson in the effects of overcrowding. Before 1995 the colony would alternate between a roost on the flanks of the Soufriere Hills volcano and another in one of the caves at the northern end of the island. For several weeks at a time, each location served as the regional shelter; from there the entire colony would fan out to mob the fruiting trees in the vicinity. (Archaeological evidence suggests that Amerindian populations as long ago as A.D. 200 took culinary advantage of this predictable clustering of large fruit bats.) But by 1996 the eruption had destroyed the southern roost, leaving only the northern cave as a home for the colony.

Since that time the fruit-bat population has rebounded and stabilized, but not without complications. External parasites on the bats are significantly more numerous than anyone had ever previously recorded, either on Montserrat or on any of the nearby islands. I had interpreted the bats' alternation of roost sites as a means to better exploit regional food resources. In fact, though, it may have had more to do with escaping roosts that had become heavily contaminated by blood-sucking ectoparasites. Ever since the fruit bats have been forced to take permanent residence in one location, the walls of that northern cave have been literally crawling with parasitic insects and their larvae.

So what explains the bald, toothless bat that was clamped onto my thumb in 1997? Before the onset of volcanic activity two years earlier, less than 1 percent of the fruit bats examined by biologists on Montserrat showed any sign of tooth wear or hair loss. The bats that did were elderly animals with other obvious signs of age: scarring, broken bones that had healed, arthritic joints. Yet between 1995 and 1999 the teeth of nearly half of the fruit bats we captured were worn at least half way to the gum line, and a quarter of all the bats had lost 50 percent of their hair.

Excessive dental wear is caused by

the fine, abrasive ash that blankets everything after a pyroclastic eruption. It is next to impossible for a fruit bat to avoid the grit, which adheres to the sticky fruit it eats as well as to the animal itself; even as a bat grooms itself, it gets a mouthful of the ash. For now, since the volcanic activity has at least temporarily decreased, we are finding progressively fewer bats with tooth wear. The ones that do have worn-out teeth are older animals, veterans of earlier exposures to ash. For our 2002 census it was easy to tell old bats from younger ones simply by offering them an exposed thumb.

What about the loss of fur? One might expect to find some kind of skin inflammation or skin infection associated with the loss, but not one of the hundreds of bald fruit bats we have examined has shown either. There are several other possibilities under active study: Perhaps in response to external parasites such as streblid batflies, the bats simply groom themselves until their hair falls out. Perhaps the hair loss is caused by mineral imbalances associated with the ingestion of ash. Or perhaps the bats, deprived of their preferred fruits by the pyroclastic flows, are reduced to eating foods they normally shun. The false tamarind *(Leucaena leucocephala)*, for instance, contains noxious chemical compounds such as mimosine, which induces hair loss.

As forested land on Montserrat has been lost to the volcano, both the number of species and the number of animals on the island have declined. Ten bat species lived on Montserrat before Hurricane Hugo struck in 1989. By 2002 three species that either had persisted as marginal populations or were habitat specialists—the fishing bats, yellow-shouldered bats *(Sturnira thomasi)*, and white-lined bats *(Chiroderma improvisum)*—had been locally extirpated.

That is not to say they might not return. Tropical storms and hurricanes regularly transport insects, birds, and bats from one island to another throughout the Caribbean. Once a storm drops flying animals such as bats on an island, they tend to stay put. They have no way of knowing what is out there, and a fruit bat that ventures out over the empty sea runs a big risk, given what seem to be the species' limited navigational abilities over long distances.

Two bat species that lived briefly on Montserrat in small transient populations—the yellow-shouldered bat and the white-lined bat—had previously been known only from Guadeloupe. It is likely that large storms will eventually return those and other species to Montserrat. Fishing bats are strong fliers, and could return to Montserrat on their own, probably from the neighboring islands of Antigua or Barbuda. Similar extirpations and reintroductions occur throughout the "hurricane belt" with some regularity, changes that are of great interest to those of us who study the biogeography of bats in the West Indies. We now have genetic data that also support this rare but consistent storm-blown reintroduction of new animals. The cycle suggests that the biogeography of the West Indies is far more dynamic and changeable than ecologists had previously suspected.

Tropical storms and hurricanes regularly transport insects, birds, and bats from one island to another throughout the Caribbean.

Fruit bats are critical to the rejuvenation of the forests destroyed by Montserrat's volcano, primarily because they play such a crucial role in dispersing seeds and nutrients. Hence the dramatic loss of biodiversity within the bat population jeopardizes the forests' recovery. Our plan is to document the excursions of fruit bats into marginal areas, tracking the dispersal of seeds into heavily damaged regions and the beginnings of a recovery that will take many human lifetimes.

In spite of the "inconveniences" of being blown out to sea by hurricanes or endangered by pyroclastic flows, the fruit bats of Montserrat have soldiered on. Their tenacity has given me a unique opportunity to study how animal populations respond to a variety of natural disasters. And the news is finally taking a turn for the better. My 2002 census of Montserrat's fruit bats followed the wettest spring since 1995. Several varieties of fig trees were heavy with fruit for the first time since 1995. And we were able to capture nearly three and a half times more fruit bats last summer than we had during the peak of volcanic activity in 1997. The rain, the dramatic rejuvenation of Montserrat's remaining forested areas, and a great increase in fruit bat populations are all most welcome.

In fact the entire island—its resilient people, forests, and wildlife—seems well on its way to recovery from a very long volcanic nightmare. Who knows what the future will bring to the people and bats of Montserrat? Before I returned to the vast windblown expanses of South Dakota (where my alter ego is that of university professor), I treated myself to one last night in the small village of Cudjoehead. There I was immediately struck by a strong sense of déjà vu: the beer was cold, the town throbbed with reggae music that pushed its way along the narrow streets, the warm tropical breeze that blew overhead was once again full of large fruit bats—the way Montserrat used to be.

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Extreme Forestry

What does bungee jumping say about parasitic vines?

Story by Adam Summers ~ Illustration by Mick Ellison

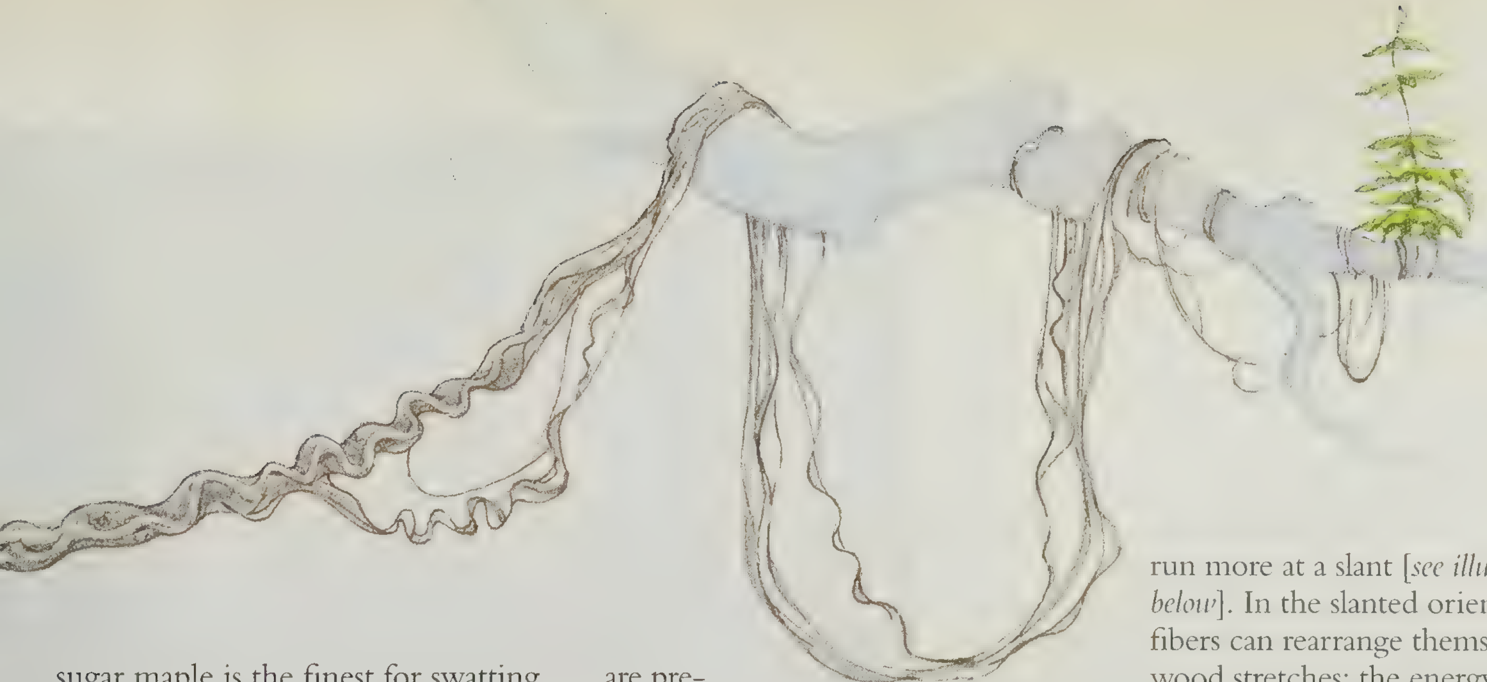
It is May, time for *naghol*—a centuries-old fertility ritual practiced on Pentecost Island in Vanuatu, in the South Pacific. The participants—the island's young men—perform land dives to obtain a blessing for their people's crops. As a crowd of islanders watches, each young participant scales a rickety scaffold of branches to a platform some seventy feet above the tilled earth. The diver pauses for a moment, then leans forward and plunges headfirst off the platform, trailing vines tied to his ankles. If he has chosen the vines well, they will pull taut and stretch like a natural bungee cord, just enough to gently arrest his fall. If he has chosen poorly, he may slam into the ground or be yanked back against the platform.

The success of such derring-do evidently depends on the material properties of lianas, or woody vines. But how can woody vines stretch like oversize rubber bands? To answer that question, let's go to the other side of the world: to the forests of French Guiana on the northern coast of South America, where a German investigator, Thomas Speck, gingerly tests the strength of a kind of liana called monkey ladder *(Bauhinia guianensis).* Satisfied that the vine is sound, he hoists himself off the ground and swings back and forth on the vine like Tarzan of the apes. Speck and his colleague Benedikt Hoffmann, both biomechanicists at the University of Freiburg in Germany, analyze the peculiar material properties of woody vines. They are working to find out what makes the structure of lianas different from that of trees and shrubs—hence what makes lianas usable as elastic, weight-bearing rope.

Wood is a composite material made of two principal substances: cellulose, a complex carbohydrate that is the chief structural part of most plant-cell walls; and lignin, which binds the components of cell walls together. The same kind of pairing shows up in familiar man-made products: in the modern tennis racket, for instance, carbon fibers are mixed together with epoxy. The fibers provide tensile stiffness and strength, while the epoxy keeps the fibers properly oriented and binds them together.

Although composite materials can be made artificially, the properties of wood cannot be duplicated. Osage orange wood, not fiberglass, still gives the best power and feel for archers' bows; old-growth spruce adds vibrancy and color to the tones of the finest violins; and many major-league baseball players, long accustomed to bats made from ash, now swear that

Monkey ladder (Bauhinia guianensis)



sugar maple is the finest for swatting one out to the center-field bleachers.

Lianas are woody vines that parasitize trees for structural support. A liana climbs its host tree, called a trellis, by laying down a network of tendrils, spikes, and hooks. Thus, it reaches the light of the upper canopy without having to invest in building up enough wood in its stem to support its weight. In American tropical forests, lianas may account for nearly half the leaf productivity, yet they amount to less than 5 percent of the biomass.

But a liana does not begin life as a parasite. It grows on its own until it finds a tree to cling to. Monkey ladder can reach a height of nearly six feet as a freestanding shrub. But when it finally finds a trellis, the vine begins to grow rapidly, the stem cross section becomes thicker and rectangular, and the material properties of the stem change radically.

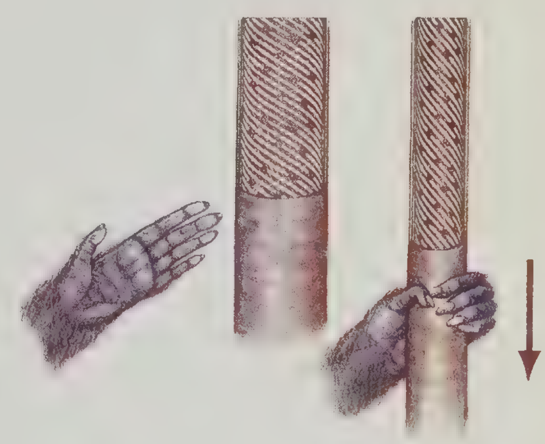
The wood of a self-supporting monkey ladder shrub can be as stiff and dense as the hard, heavy wood of black locust trees that commonly occur in North American deciduous forests. The wood developed by the vine during the climbing, parasitic phase is less dense—the vessels in the wood that conduct water up the stem become much larger, and the wood itself absorbs more water. The increased water content makes the mature monkey ladder vine as much as three times more elastic than the shrub. So it's not surprising that the land-diving ceremony on Pentecost Island is held just after the wet season, when the vines are presumably filled with water and become most springy.

According to Speck's work on South American lianas, if a land diver were attached to a fifty-foot-long vine of shrub wood, it would stretch only five more feet. That would leave the diver far short of the ground (recall that the towers in the *naghol* ceremony are seventy feet high). But perhaps more important to the diver, the vine's arrest of his fall would be so abrupt that he would risk injury to both ankles (assuming the sudden loading didn't simply break the vine).

How do lianas make the transition from shrub to creeper? Speck and Hoffmann have shown that both monkey ladder and an unrelated South American liana, *Condylocarpon guianense,* undergo a marked drop in the cellulose, or fiber, content of the wood. (The amount of lignin—the epoxy analogue—remains the same in both kinds of liana.) But in all its stages of life *Condylocarpon* contains between 10 and 20 percent less cellulose than does the monkey ladder, and is about a third as stiff. Those data suggest that cellulose content is critical to stiffness.

A second change that occurs in the parasitic phase is the arrangement of the fibers, at least in *Condylocarpon.* In its self-supporting, shrub phase, the wood fibers of *Condylocarpon* are oriented longitudinally, nearly parallel to the stem's long axis. In contrast, when the plant becomes a creeper, the fibers run more at a slant [*see illustration below*]. In the slanted orientation the fibers can rearrange themselves as the wood stretches; the energy absorbed as the fibers shift is either dissipated as frictional heat or stored as potential energy in the wood's elastic tissue. Either way, the vine does not break.

Now that Speck and his colleagues are getting to the root, so to speak, of the changes in vines as they shift from shrub to creeper, the next step is to understand the genes that drive the changes. That understanding might one day make it possible to fine-tune the properties of wood to our liking. And what's next? High-tech tennis rackets and affordable Stradivarius-like violins that, quite literally, grow on trees?



An artist's conception of the parasitic liana Condylocarpon guianense *shows the wood both unloaded (left) and under load. The cellulose fibers in the wood, shown in white, shift their orientation toward the vertical as the monkey pulls on the vine. As it stretches, the vine becomes thinner and as much as 30 percent longer.*

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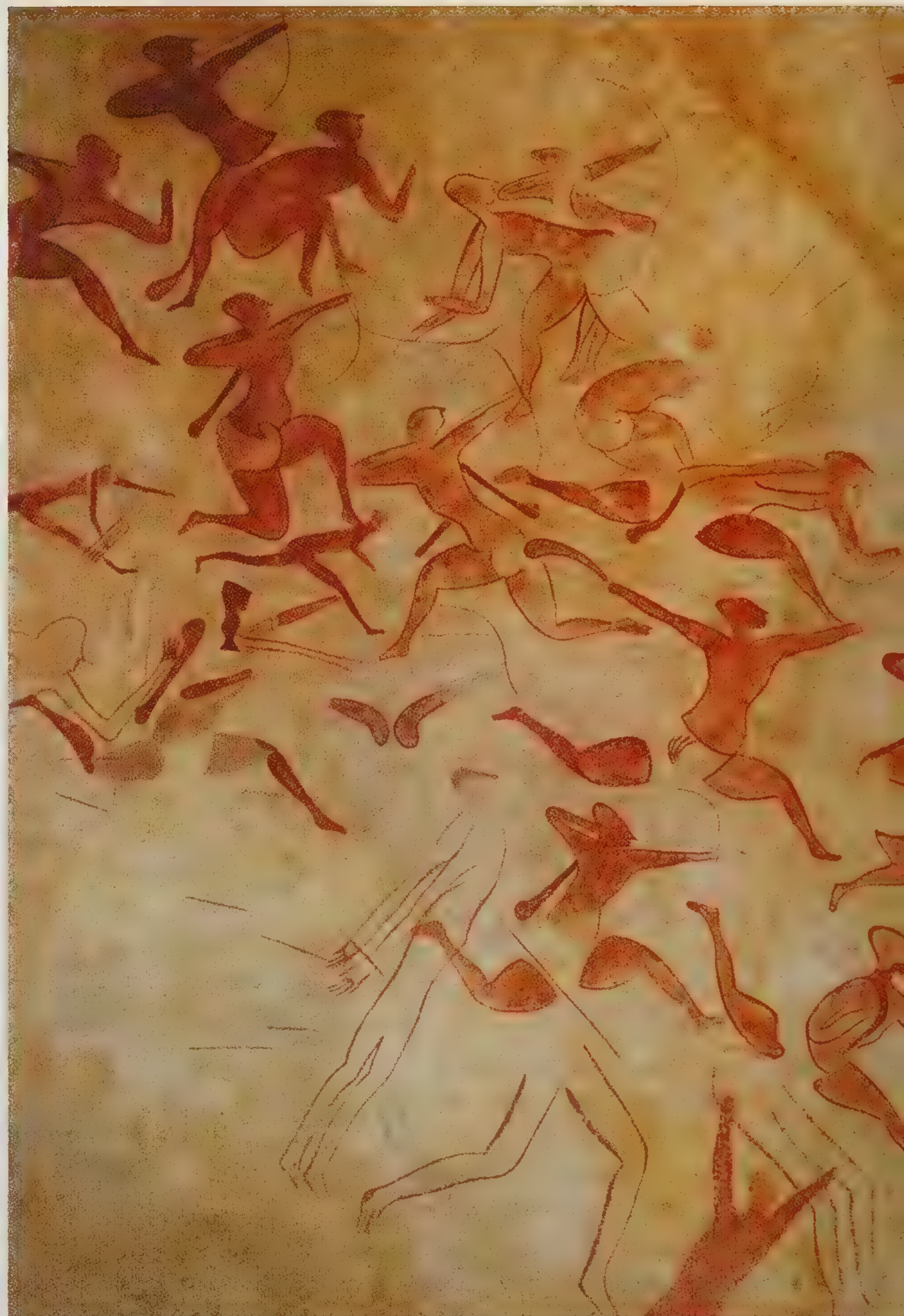


THE BIRTH OF WAR

Thirty years ago all the anthropologists studying war would have fit into one small room. Granted—and guaranteed—that room would frequently erupt in heated debate, but few outside would notice or care. Tribal warfare? Exotic, maybe, but so what? Anthropologists see war as potentially lethal violence between two groups, no matter how small the groups or how few the casualties. But how much light could such a broad definition of conflict, or cases of precivilized human strife, shed on modern warfare, the struggles that have flared in Iraq, Kosovo, Rwanda, Vietnam, Korea—and on and on?

How times have changed! The anthropological study of war has expanded and matured. Ideas from academic debates are finding their way into foreign policy journals and, yes, the mass media. The questions raised by anthropologists and the once-academic disputes within the discipline have become important public issues, to be debated by pundits and politicians.

To appreciate how much things have changed, consider how the understanding of one famous ethnographic case has been transformed: that of the Yanomami of Venezuela and Brazil. Following the publication of Napoleon A. Chagnon's study *Yanomamö: The Fierce People,* in 1968, the book began to appear frequently and prominently on lists of readings for college students in introductory anthropology—often the only anthropology they would ever learn. And what an object lesson! Engaged in endless wars over women, status, and revenge, the Yanomami were supposed to exemplify the natural human condition of eons past. Some people took Chagnon's work to imply that aggression is in our genes—disturbing news if true.

In 1974 the anthropologist Marvin Harris offered a different view. Yanomami warfare, Harris argued, was an adaptive response from a population

A rock painting in Tassili n'Ajjer, a Saharan plateau in southeastern Algeria, illustrates a battle between two prehistoric groups. Armed mostly with bows and arrows, the group at right braces in firing position for an assault by the group at the left. The scene was created sometime between 6,000 and 4,500 years ago, perhaps by nomadic cattle herders.

An archaeological survey concludes that warfare, despite its malignant hold on modern life, has not always been part of the human condition.

By R. Brian Ferguson

stressed by limited food resources, specifically game animals. But detailed examination of Yanomami ecology failed to support Harris's hypothesis.

In 1995, in *Yanomami Warfare: A Political History,* I described how the Yanomami have been coping with European intrusions since the 1700s. As I read the evidence, Yanomami wars were tightly linked to changes in the European presence. Recent wars, including the ones described by Chagnon, seemed to have been fought over access to steel tools and other goods distributed by Westerners. Yet despite such basic disagreements within anthropology, the discussion of the Yanomami remained confined to academic circles.

Then came a media frenzy. In the fall of 2000, Patrick Tierney, a journalist, published *Darkness in El Dorado: How Scientists and Journalists Devastated the Amazon.* The book essentially blamed Chagnon himself for instigating war. Now it was the anthropologists' turn to be fierce. Opponents and defenders of Chagnon exchanged bitter broadsides. Not a few anthropologists felt that the resident missionaries, for all their good intentions, were more at fault than any anthropologists. One outcome of the episode, though, is that no one paying attention to this controversy still claims that Yanomami wars can be understood without taking into account the tribe's highly disrupted historical circumstances.

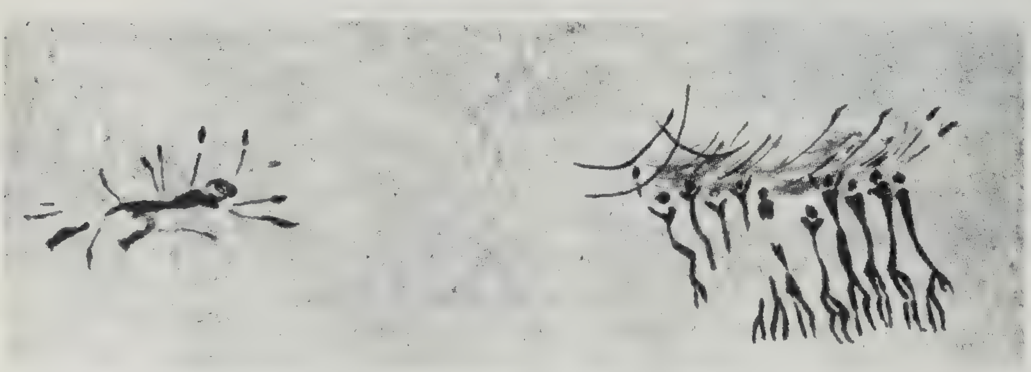
What is more, studies that go far beyond the Yanomami are questioning the idea that war has always been part of the human condition. It looks as if, all around the world, what has been called primitive or indigenous warfare was generally transformed, frequently intensified, and sometimes precipitated by Western contact. A collection of historical studies that I edited in 1992 with Neil L. Whitehead, an anthropol-

ogist at the University of Wisconsin–Madison, concludes that such changes often took place in far-flung "tribal zones," even before literate observers arrived on the scene. Indigenous warfare recorded in recent centuries cannot be taken as typical of prehistoric tribal peoples (see *War in the Tribal Zone: Expanding States and Indigenous Warfare*). We need archaeology to tell us about ancient war.

In 1996 the issue took a new turn with Lawrence H. Keeley's book *War before Civilization*. Keeley, an archaeologist at the University of Illinois at Chicago, compiled archaeological cases of some of the worst violence known, thereby creating the impression that these examples were typical, that humans have always made war. As he told the journal *Science*, "War is something like trade or exchange. It is something that all humans do." Here I must unequivocally disagree: in my view the global archaeological record contradicts the idea that war was always a feature of human existence; instead, the record shows that warfare is largely a development of the past 10,000 years.

Five layers of human skeletons, some decapitated and some showing signs of struggle that suggest the victims were thrown in alive, fill the bottom of a water well excavated at the site of Chien-kou, near Handan, about 250 miles southwest of Beijing. The site, belonging to China's Longshan culture and dating from about 4,400 years ago, provides strong evidence of warfare between communities.

In the new book *Constant Battles: The Myth of the Peaceful, Noble Savage* (written with the writer Katherine E. Register), Steven A. LeBlanc, an archaeologist at Harvard University, confidently asserts that wherever good archaeological evidence exists, there is "almost always" evidence of warfare, that "*everyone* had warfare in *all* time periods." LeBlanc has a theory for his sweeping conclusion. Contrary to a commonly held view, he argues, pre-state peoples were never "true conservationists." They degraded their resources, and as their numbers grew, they suffered food scarcity and were drawn into war. Basically, it's Malthus with ethnographic detail.



An execution appears to be the subject of this painting in Remigia cave, in the eastern Spanish province of Castellón. Such depictions caution archaeologists that when they find a single skeleton with an embedded arrow point, it may not be a sign of warfare. The original painted image, from which this reproduction was made, may be 7,000 years old.

But what kind of archaeological evidence could show that war was waged? Lots. The best evidence comes from collections of skeletons, which can still bear witness to the violence of war: the embedded points of spears, arrows, or other weapons [*see photograph on opposite page*], depression fractures or scalp marks on skulls, "parry fractures" of forearms, and solitary skulls or bodies missing skulls (strongly suggesting that war trophies were taken). Mass burials or the absence of burial, as well as disproportionately few battle-age men in cemeteries, are also signs of war. Of course, such finds, particularly if the evidence is a single skeleton, could represent a murder, an execution, or an accident—hence a "false positive" as a piece of evidence about early tribal warfare. But nothing like tribal warfare could be going on without leaving some signs in a good collection of skeletons. If the collection comprises multiple examples of such evidence, it pretty conclusively demonstrates war.

Settlement patterns—such things as defensive walls and defendable locations or nucleated populations with empty buffer zones—also provide significant evidence of warfare. Violent destruction of a settlement is a telling clue. Specialized war weapons may be lacking—after all, war can be fought with such ordinary tools as adzes or hunting spears. But implements such as maces and daggers are usually for killing people, and when found, they are fairly de-

finitive. Paintings or carvings on walls can provide graphic evidence of combat. Many peoples did not leave recoverable representations of human beings, but if such depictions are preserved, they can make a persuasive case. In short, when and where the archaeological recovery is good, with many settlements and many skeletons, war can usually be detected—not in every single case, certainly, but in a good number of them. That is the basis for supposing that archaeology can contribute to some of our most basic questions about war.

I am midway through a global survey of such early evidence. What does the record show? Many hominid remains once thought to establish the most ancient evidence of homicide or cannibalism were actually gnawed by predators or just suffered postmortem breakage [*see "The Scavenging of 'Peking Man,'" by Noel T. Boaz and Russell L. Ciochon, March 2001*]. Some cases of ancient cannibalism have been confirmed, but there is nothing to tell us that the remains in question were casualties of war.

The earliest persuasive evidence of warfare uncovered so far comes from a graveyard along the Nile River in Sudan. Brought to light during an expedition in the mid-1960s led by Fred Wendorf, an archaeologist at Southern Methodist University in Dallas, Texas, this graveyard, known as Site 117, has been roughly estimated at between 12,000 and 14,000 years old. It contained fifty-nine well-preserved skeletons, twenty-four of which were found in close association with pieces of stone that were interpreted as parts of projectiles. Notably, the people of Site 117 were living in a time of ecological crisis. Increased rainfall had made the Nile waters run wild, and the river dug its way deeply into a gorge. The adjacent flood plain was left high and dry, depriving the inhabitants of the catfish and other marshland staples of their diet. Apart from Site 117, only about a dozen *Homo sapiens* skeletons 10,000 years old or older, out of hundreds of similar antiquity examined to date, show clear indications of interpersonal violence.

In northern Australia, rock art depicts what appear to be duels between two or a few individuals as early as 10,000 years ago. Large group confrontations—war—appear by 6,000 years ago. Climate change was a factor here too, as rising sea levels gradually submerged a vast plain that once connected Australia and New Guinea.

The ancient Middle East provides some of the best evidence for the emergence of war from a warless background. Extensive remains have been found of the Natufian hunter-gatherers, who lived between about 12,800 and 10,500 years ago in what are now Israel, the West Bank, Jordan, Lebanon, and Syria. Careful analysis of 370 skeletons has turned up only two that show any signs of trauma, and nothing to suggest military action. The first walls of Jericho (dating from between 10,500 and 9,300 years ago) were once taken as conclusive evidence of war, but they are now understood to have been built for flood control, not defense.

Pierced by a bone arrowhead, the skull of a thirty-five-year-old man was discovered in eastern Denmark. Another arrowhead pierced the man's breastbone. Was this death, 5,000 years ago, that of a warrior, a criminal, or perhaps a sacrificial victim? Although the violent death is apparent, its interpretation is uncertain.

There is a certain ironic logic, given recent events, that the regular practice of warfare that has continued without interruption down to the present began about 10,000 years ago in what is now northern Iraq. Evidence from three early farm-

ing sites, the earliest from Qermez Dere, includes maces, arrowheads found associated with skeletons, defendable locations, and village defensive walls. That's war—the true "mother of all battles."

Signs of war appear beginning 8,000 years ago along mountain routes through southern Turkey. Along the southern Anatolian coast, a specialized fort—not just a walled village—has been unearthed at İçel; the fort was built around 6,300 years ago, then destroyed and later resettled by a different culture. The early record along the Nile in what is now Egypt was wiped out by the river's erosion, but when the record picks up again, about 6,300 years ago, maces similar to those found in Mesopotamia are present. Far upriver, near Khartoum, what may have been maces show up 2,000 years earlier, even before agriculture began in that area.

Two Bronze Age figures raise their axes on a rock outcropping in Sweden known as the Fossum panel. Whether the scene, carved about 900 B.C., represents a battle, a ritual, or a dance, by this time war had become a cultural preoccupation all across Europe. The paint that highlights the carving is a recent addition.

In Central Asia, east of the Caspian Sea, the remains of settled hunter-gatherers and early farmers show no signs of war, but war was clearly going strong by 5,000 years ago. In the high country of what is now Pakistan, farmers began to put up walls at least 6,000 years ago.

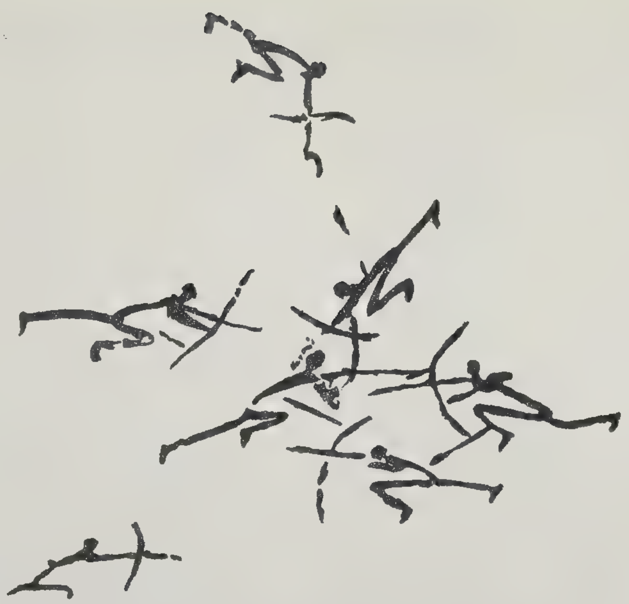
The archaeological record in China shows that though millet was under cultivation at least 8,000 years ago, no signs of war appeared for more than a thousand years after that. Starting 7,000 years ago, in one Neolithic cultural tradition, deep ditches were dug around villages, some accompanied by palisades. Elsewhere in China, except for a single skeleton with a point embedded in its thigh, there are no hints of war until at least 4,600 years ago. Then, rammed earthen walls and other signs of war occur throughout the core areas of historical China. One village well contained layers of scalped and decapitated skeletons.

In Japan, intensive agriculture came in with migrants from the mainland about 2,300 years ago. Archaeologists have excavated some 5,000 skeletons that predate the intrusion, and of those only ten show signs of violent death. In contrast, out of about 1,000 postmigration excavated skeletons, more than a hundred show such signs.

Evidence from Europe offers a clear window into preagricultural practices. There is no firm evidence of war for thousands of years during Paleolithic times—though some scholars see suggestive indications in a few places. After 10,500 years ago, however, as the population of foragers became larger and more settled, several sites show individual violence, and others show the more collective casualties that signal war. Still, the evidence of violence is present at only a small minority of all excavated sites. Beginning around 6,500 years ago, however, fortifications, embedded points, and even clear signs of village slaughters become common. By the Bronze Age, 2,000 years later, war and weaponry had become a veritable cult.

North America presents a highly complex and regionally divergent picture. Kennewick Man, a skeleton unearthed in Washington state and considered between 7,500 and 9,200 years old, contains an embedded stone point. But because the skeleton is an isolated find, the injury is difficult to interpret. On the coast of the Pacific Northwest, skeletal trauma and other signs of conflict begin to appear about 4,200 years ago in the northern regions, but show up farther south only many centuries later. Many of the excavated skeletons from the ancient eastern woodlands show signs of violence. In a few cases multiple individuals were involved, including one site in Florida dating from more than 7,000 years ago. Still, such cases remained extremely un-

usual until 5,000 years ago. In the southern Great Plains, out of 173 skeletons reported from before A.D. 500, only one indicates homicide, a woman killed by two blows to the head. The first clear evidence of warfare in the Southwest dates from less than 2,000 years ago, and it is quite dramatic. At least two-thirds and perhaps all of the ninety-odd individuals interred in a cave in southern Utah were killed.



Archers clash in a cave painting from Morella la Vella in eastern Spain. The composition, perhaps 7,000 years old, seems to depict a flanking maneuver by the figure on top. This image is a tracing of a photograph.

Roughly speaking, that is where my survey leaves off. But my preliminary work leads me to expect no major surprises from Africa, Mesoamerica, Oceania, or South America. In sum, if warfare were prevalent in early prehistoric times, the abundant materials in the archaeological record would be rich with the evidence of warfare. But the signs are not there; here it is not the case that "the absence of evidence is not evidence of absence."

So how did peaceful tribal peoples of the distant past turn into the war-prone societies observed in recent centuries? Specific causes are elusive, but I see five preconditions that, in varying combinations, contributed to the onset of warfare in prehistoric times. One was a shift from a nomadic existence to a sedentary one, commonly though not necessarily tied to agriculture. With a vested interest in their lands, food stores, or especially rich fishing sites, people no longer could walk away from trouble.

Another precondition was a growing regional population and probably, in consequence, more competition for resources. Third was the development of social hierarchy, an elite, perhaps with its own interests and rivalries. Fourth was an increasing long-distance trade, particularly in prestige goods: something else worth fighting over. Finally, the first appearance or later intensification of war was often associated with a severe climatic change that broke down the subsistence base.

Raymond C. Kelly, an anthropolgist at the University of Michigan in Ann Arbor, in his book *Warless Societies and the Origin of War,* has detected what may be another important pattern in the origins of war. In examining the ethnographic literature to compare hunter-gatherers who make war with those who do not, he finds a pattern: Among the few known cases of warless societies of hunter-gatherers, social organizations do not extend beyond family and a loose, flexible network of kin. In contrast, hunter-gatherer societies that make war have larger and more defined groupings such as clans. The existence of bounded groups makes for a sense of collective injury and desire for collective retaliation.

Over the millennia, tribal warfare became more the rule than the exception. As the preconditions for warfare (permanent settlements, population growth, greater social hierarchy, increased trade, and climatic crises) became more common, more tribal peoples in more areas adopted the practice. That development in itself spread warmaking to other groups. Once ancient states arose, they employed "barbarians" on their peripheries to expand their empires and secure their extensive trade networks. Finally, the European expansion after 1492 set native against native to capture territory and slaves and to fight imperial rivalries. Refugee groups were forced into others' lands, manufactured goods were introduced and fought over (as with the Yanomami), and the spread of European weapons made fighting ever more lethal.

When I began studying war in the mid-1970s, I was trained in an approach called cultural ecology, which argued along the lines that Steven LeBlanc

Maces, skeletons with arrowheads, and village defensive walls have been discovered in Iraq, all signs of the true "mother of all battles," 10,000 years ago.

does today. Population pressure on food resources—land, game, herd animals—was seen as the usual cause of indigenous warfare. In some cases the theory did work. Among the peoples of the Pacific Northwest Coast prior to the depopulation of the nineteenth century, groups fought to gain access to prime resource locations, such as estuaries with good salmon streams. But in far more cases around the world, such as that of the Yanomami, warfare could not be linked to food competition.

Today, under the rubric "environmental security," many nonanthropologists who work on issues of international security embrace that ecological view. Recent outbreaks of violence, they argue, may be rooted in scarcities of subsistence goods, fueled by growing populations and degraded resources (such as too little and eroded cropland). But when you examine the cases for which that interpretation seems superficially plausible—the conflicts of the past several years in Chiapas, Mexico, for instance, or in Rwanda—they fail to confirm the "ecological" theory.

A chariot with warriors is among the trappings of warfare included on the so-called Standard of Ur, a Sumerian object dating from about 2500 B.C. By that time, war was a normal practice between rival city-states.

We anthropologists are just beginning to bring our experience to bear in the environmental security debate. What we find is that if a peasant population is suffering for lack of basic resources, the main cause of that scarcity is an unequal distribution of resources within the society, a matter of politics and economics, rather than the twin bugbears of too many people and not enough to go around.

Anthropology can offer an alternative view on such terrible disasters as the Rwandan genocide or the civil wars in the Balkans. Case studies of modern-day conflicts show that a broad range of factors may be interacting, including subsistence needs and local ecological relations, but also political struggles over the government, trends in globalization, and culturally specific beliefs and symbols. Moreover, when hard times come, they are experienced differently by different kinds of people. Who you are usually determines how you're doing and where your interests lie: identity and interest are fused. Once a conflict gets boiling and the killing starts, all middle grounds get swept away, and a person's fate can depend on such simple labels as ethnic, religious, or tribal identity. The slaughter of Tutsis in the Rwandan genocide of 1994 is only one of the latest examples of that horrific effect. But such differences are not the cause of the conflict.

My view is that in most cases—not every single one—the decision to wage war involves the pursuit of practical self-interest by those who actually make the decision. The struggle can be joined over basic subsistence resources, but it can just as easily erupt over goods available only to elites. The decision involves weighing the costs of war against other potential hazards to life and well-being. And most definitely, it depends on one's position in the internal political hierarchy: from New Guinean "big men" to kings and presidents, leaders often favor war because war favors leaders.

Of course, those who push toward war do not make their case in terms of their own selfish interests. Around Amazonian campfires and within modern councils of state, their arguments invoke collective dangers and benefits. But even more, those advocating war always define it in terms of the highest applicable values, whether that involves the need to retaliate against witchcraft, defend the one true religion, or promote democracy. That is the way to sway the undecided and build emotional commitment. And always, it is the other side that somehow brought war on.

Such drumbeating is not only, or even primarily, cynical manipulation. Perhaps owing to a basic human need for self-justification, those who start wars usually seem to believe in the righteousness of their chosen course. It is that capability that makes human beings such a dangerous species. □

The White House ruins in Canyon de Chelly National Monument, Arizona: Archaeological investigation shows that this particular cliff dwelling—although seemingly designed for defensive purposes—was a ceremonially significant complex built between A.D. 1050 and 1150, a century before deteriorating climatic conditions in the Southwest led to intense warfare.

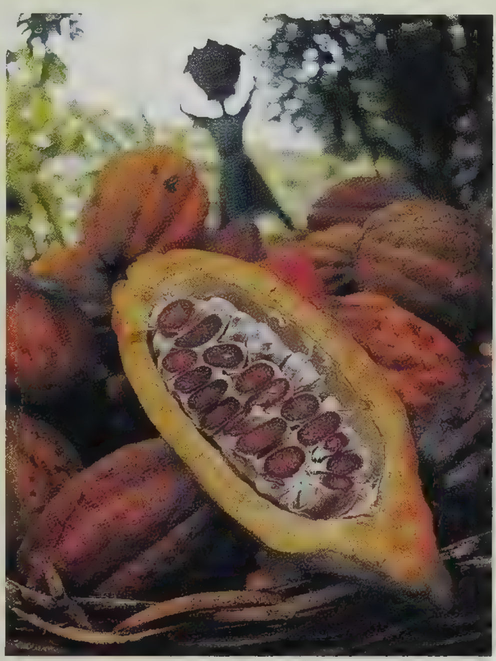
Charles Plumier, *Cacao, from a manuscript on plants and civilization in the Antilles*, c. 1686

The Chocolate Tree

Growing cacao in the forest can provide a living to small farmers and a habitat to diverse creatures.

By Robert A. Rice and Russell Greenberg

To most North Americans the word "chocolate" probably conjures visions of a fragrant, nut-studded brown slab, or a box full of small but elaborate variations on gooeyness, or one of those outrageous dark desserts with names such as "mud pie" or "death by chocolate." Few of us who savor and consume such delights think about moist, lush foliage, the shrieks of toucans and parrots, or a Maya ruler from the seventh century A.D. sipping chili-spiked cocoa froth.



Cacao beans in a pod, Grenada

But perhaps we should. *Theobroma cacao*—the tree whose giant pods contain the seeds that, when roasted and then ground, become the powder that is the basis of chocolate—is an evolutionary product of the vast tropical rainforests of the New World. Indigenous peoples domesticated the tree in the northern Amazon basin and seemingly independently somewhere in what is now southern Mexico, Guatemala, or Belize (recent genetic work, however, suggests that the Mesoamerican domesticated stock originated in South America). To those fortunate people, the cocoa drink made from cacao was, as reflected in the genus name, indeed the "food of the gods."

Today, however, this forest tree is cultivated far from its birthplace. In 2002 more than 40 percent of the world's cacao came from Côte d'Ivoire. Ghana, Indonesia, and Nigeria together produce about 33 percent, Brazil less than 5 percent. But though well-heeled *norteamericanos* may be laying down a ten-dollar bill to pay for half a dozen hand-crafted chocolate delights, the world's average rate for cacao beans in 2002 was not much more than eighty cents a pound, and many farmers who grew the beans were paid far less.

Yet a look at the biology, history, ecology, and economics of the cacao tree—and the industry that has sprung up around it—shows that unlike many products of the developing world that the developed world enjoys, cacao can be a relatively benign crop. It can be grown economically on small farms, bringing individual farmers into the world's cash economy without destroying their independence and self-determination. As a shade-tolerant tree, it can also be cultivated under a canopy of larger trees already living in the tropical forest; clear-cutting is actually detrimental to a sustained crop yield. That means that cacao growing, albeit not entirely without harm to the forest ecosystem, is far less destructive than most other forms of cultivation. Preserving the canopy, in turn, helps in maintaining populations of indigenous birds and other forest animals, and in pulling carbon dioxide out of the air. Inside the wrapper of this food we

have come to take for granted is a complex web of interrelating factors that ecologists are only beginning to understand.

The cacao tree grows naturally in the shaded, humid understory of lowland tropical forest, reaching heights of some twenty feet. Twenty or thirty large, gently fluted pods grow directly from the tree's trunk and branches, dangling like holiday ornaments. Each pod is between six and twelve inches long, its hue orange or reddish orange by the time it matures. Inside the pod are two or three dozen seeds—the cacao beans—surrounded by a sweet, milky-white gelatinous pulp that is the main ingredient for a South American drink.

The cacao beans themselves, which are dull brown on the outside and a striking purple within, are an unlikely resource for the dessert-hungry people of the world. A mere brush against the tongue imparts a strong and bitter flavor. The pods and their beans probably evolved as they did by taking advantage of the cravings of nonhuman primates. The sweet pulp is an attractive food, encouraging the animals to remove the pods. The beans, or seeds, however, are enriched with distasteful alkaloids, and thus are discarded wherever the pulp is consumed. The combination virtually guarantees seed dispersal.

Cross section of forest in a small West African cacao farm includes trees at three distinct levels. Among the tallest are such plants as (left to right) oil palm, Terminalia (a source of timber), and rubber. At the second level are trees that offer the cacao farmer a further hedge against fluctuations in the price of cacao: depicted here (left to right) are guava, avocado, mango, orange, and coconut. At the lowest level are the cacao trees (the three trees in the foreground with reddish pods), which thrive in the shade. The planted, mixed forest, known as polycultural farming, maintains a level of biodiversity much greater than does plantation cultivation of cacao as a single crop.

The native cacao tree also depends on minuscule flies, attracted by the overripe pods that fall to the ground and rot around its base. The flies require large pieces of moist tropical detritus (such as rotting cacao pods) to carry on their own life cycle; while thus occupied, they pollinate the tree's small flowers, which develop into the next generation of pods. Because of that natural history, cacao is much more likely to be pollinated in a forest with a moist, messy understory than in a commercial plot cleared or raked by human tools.

Cacao has been cultivated for hundreds if not thousands of years, and so has been subjected to plenty of ad hoc horticultural experimentation. Even before European contact, cacao trees had been planted far from their natural origins, and their beans were a treasured Mesoamerican resource. By the time of contact, according to the early sixteenth-century Spanish chronicler Gonzalo Fernández Oviedo y Valdés, the beans had become so widely cultivated that they were used as money: to acquire "gold, slaves, clothing, things to eat and everything else," Valdés wrote. Between the late seventeenth and the late nineteenth centuries, the heyday of Europe's colonial empires in the tropics, cacao joined coffee and rubber as crops transplanted to distant shores.

All three of those transplants proved highly successful. They benefited, at least initially, from the enforced separation between the plant and its coevolved insect pests and diseases. Coffee, native to tropical Africa, is now grown for export in Brazil, Colombia, and Vietnam; rubber, native to South America, is cultivated in Malaysia. For cacao, the heavy-hitting region for production quickly became West Africa.

Like its sister crop coffee, cacao is still commonly grown in a forest or forestlike setting called an agroforest, where shade trees tower over cacao plants that have been pruned to harvestable height. Botanists classify such agroforests (at least for cacao or coffee) according to the stature and diversity of

the shade-tree canopy. In "rustic" cacao farms, large canopy trees in the original tropical forest are thinned out, to enable more light to penetrate to lower heights. Cacao trees are simply cultivated beneath the remaining shade trees. This is in considerable contrast to the large, technologized "zero-shade" cacao plantations, which apply generous amounts of highly toxic herbicides, such as paraquat, and potent insecticides such as endosulfan.

The shade-tolerant cacao tree can be cultivated beneath a canopy of taller trees, sparing existing tropical forest from clear-cutting.

But most cacao today is grown on so-called polycultural farms, under planted shade—a somewhat more managed environment than the rustic farms, but still far more biodiversity-friendly than the zero-shade plantations. In a polycultural system the farmer selects and manages much of the canopy, or even all of it. A single species, usually a fast-growing legume, supplies most of the shade. Trees that yield fruit for human consumption often form a second, intermediate canopy. Beneath it all are the low-growing cacao trees [*see illustration on opposite page*].

To be fruitful, a cacao tree must get individual attention—something the family farm and the small farmer are best suited to provide. Less than a third of the cacao flowers become fruit—in other words, pods—and the careful cultivator will remove defective pods throughout the growing season. Not surprisingly, hired hands on huge plantations are sparing with such tender loving care. Furthermore, large areas planted with a single crop give rise to serious agronomic problems of their own. The typical smallholder's practice of growing cacao along with an array of shade trees reduces such difficulties.

Small and medium farms of all kinds are often more productive—in terms of total useful product per unit area of land—and cacao farms are no exception. There is no big secret about what makes that so. Small peasant producers simply must work harder and smarter if they are to survive. Tied to the land, with only the occasional chance to supplement their agricultural earnings with gainful off-farm labor, small farmers are highly motivated to anticipate (and, as much as possible, to mitigate) the risks of farming: natural forces such as weather, insect infestations, and disease, and human (but still uncontrollable) factors such as export-price fluctuations and societal upheavals.

Traditional rustic and polycultural cacao systems seem well suited to cope with such risks. Part of their success comes from diversification: the multilayered forest yields not only cacao beans but also a cornucopia of other products. Farmers can harvest avocados, bananas, breadfruits, mangoes, and oranges, as well as medicinal plants, rubber, and timber. Harvesting wood from a traditional cacao farm has the added benefit of protecting other extant forests from the ax. And when cacao bean prices are low, a farm's noncacao products can still supplement the household diet and generate cash at nearby markets. Finally, polycultural cacao farms that are abandoned when world cacao prices fall or disease attacks the trees may devolve into patches of secondary forest, a habitat that remains conducive to preserving biodiversity.

Today some 17 million acres worldwide are planted in cacao, an increase of 60 percent since the early 1960s—when the North American dessert

The pink-legged graveteiro, first recorded scientifically in 1996, forages in canopy trees that shade cocoa plantations on Brazil's Atlantic coast. A juvenile is at left, an adult at right.

choice was far more likely to be cherry pie à la mode than chocolate mousse. Production of cacao beans approached three million metric tons in 2002. On a global scale, about 90 percent of all cacao farmers are "small"—defined as holding less than twenty-five acres. In some nations, such as Ghana and Cameroon, "small" almost certainly refers to a farm of less than half that area. Plantation farming was particularly popular in Malaysia, where in the early 1990s total cacao acreage soared to 750,000. But large-scale farming proved unsuccessful, and so most of the country's 125,000 acres of cacao today are small-scale farms.

A fruiting cacao tree, Belize: Cultivated trees are pruned so that the pods are at a convenient height for harvesting.

In 1996 ornithologists announced the discovery of a new species of Neotropical ovenbird, the pink-legged graveteiro *(Acrobatornis fonsecai)*, within the rustic cacao farms of the state of Bahia, Brazil. An endangered monkey, the golden-headed lion tamarin, had already been spotted in the same habitat. Those sightings were turning points for conservation biologists. After decades of focusing on pristine habitats, the biologists began to pay increasing attention to agricultural settings. Part of the shift came from their realization that, in many areas, agroforests and forest fragments are all that remain of the original, vast forestlands. Cacao farms quickly came to be regarded as preservers of biodiversity.

After decades of looking to pristine habitats to preserve biodiversity, biologists are noticing the potential value of agricultural settings.

Surveys of the flora and fauna of rustic cacao farms in West Africa have been conducted since the 1950s, but the recent sightings of rare birds have brought new energy to the fieldwork. We and our colleagues at the Smithsonian Migratory Bird Center, as well as other groups working in Brazil, Central America, the Dominican Republic, Mexico, and West Africa, have consistently found greater diversity of species in the agroforests than we can document on other kinds of agricultural lands. Agroforests still harbor such forest species as bats, canopy birds, and migratory birds.

Compared with natural forest, of course, even agroforest lands are generally depauperate. The main casualties are tree species characteristic of old-growth forests. Such trees appear doomed to vanish because regeneration is unlikely wherever the understory has been highly altered. With their disappearance comes the disappearance of the coevolved fauna: large mammals and understory birds native to pristine forests are absent in the agroforest. For that reason, the rustic cacao farm is probably not an ecologically stable system. But the findings of the biodiversity surveys suggest that even some of the small-scale polycultural cacao farms offer shelter to many otherwise doomed forest organisms. Perhaps the best hope for the future is a polycultural system developed out of a combination of traditional practices and modern research, planted with shade trees that are valuable to wildlife as well as people.

For the past decade, those of us at the Smithsonian Migratory Bird Center have been surveying the composition and diversity of birds in southeastern Mexico, both in natural and human-created systems. Two quite different kinds of cacao farms are included in the survey. The first are small, rustic farms in a "buffer zone"—a belt of well-forested but still partly cultivated land—surrounding the completely uncultivated 1,300-square-mile Montes Azules Biosphere Reserve in the Selva Lacandona, a huge lowland tropical forest

in the Mexican state of Chiapas. The second are small, polycultural, planted-shade farms in the lowlands of the state of Tabasco, on the coast of the Gulf of Mexico. The diversity of bird species we measured on the Selva Lacandona farms is more similar to what it is in pristine forests, or at least in forests that have been only slightly altered from their pristine state. Moreover, that diversity is between one and a half and seven times as great as it is in pastoral, open, or other more traditional agricultural habitats. A quarter of the most common species—mostly forest-breeding birds, both resident and migratory—occur both in the Lacandona agroforest and in undisturbed tropical forest.

In contrast, unfortunately, Tabasco's polycultural farms support substantially fewer bird species than do the rustic farms—eighty-four compared with 142. We found virtually no forest-breeding species on the polycultural farms.

We and our colleagues have also conducted extensive surveys on the cacao farms in the Apurímac valley of south-central Peru, an area known for its production of alkaloidal crops: coffee, cacao, and coca (the last grown for both legal and illicit markets). Several decades ago, much of the low-elevation, shade-grown coffee land was converted to cacao production and then, in an attempt to control a fungal disease known as monilia pod rot, the shade canopy was removed. Years of civil war involving the Shining Path guerrilla movement left much of the zero-shade cacao abandoned. Today the area is dominated by tall scrub, particularly cacao, much of which is being brought back into production.

A harvester empties cacao pods of their seeds and pulp.

Cacao seeds and pulp are collected for carrying and weighing.

The Apurímac valley had been notable for both the diversity and uniqueness of its bird populations. We were disheartened, therefore, to sight only ninety-three species of birds (a low figure by Peruvian standards), all of which are commonplace even in disturbed habitats. Presumably even though our study area encompassed small fragments of forest and was only a few miles from more continuous stretches of woods, the many years of zero-shade cultivation had rendered the habitat inhospitable to the endemic birds. They may never return.

If cacao—appropriately grown—can do good things for biodiversity, what can biodiversity do for cacao? Both planned and unplanned diversity—what farmers put in place, as well as what just shows up—contribute to the crop's successful cultivation, often in ways biologists don't yet understand. Recent experiments with shade-grown coffee have shown that birds remove more than 70 percent of the arthropod population both from the canopy and from the understory crop plants. That number includes at least half the herbivorous insects. Ants play a complex and less well understood role: they are major predators on other arthropods, including many herbivores, but they also protect scale insects, which harm plants by living off plant juices.

Biodiversity on a cacao farm also includes towering shade trees, whose leaf litter slowly releases nutrients back into the soil, and offers an attractive habitat to a host of organisms that may be critical in the breakdown and recycling of the nutrients. If

the shade trees include legumes, as is the case in many polycultural cacao farms, bacteria that live symbiotically in their roots supply the soil with usable nitrogen. The shade canopy also shields understory plants from the relentless tropical sun, as well as from the physical impact of driving tropical rains, thus reducing soil erosion. The diversity of species that follows from the presence of shade trees undoubtedly helps control certain pests and pathogens as well; taken together, the elements of the system embody the ecological mantra that diversity enhances stability. It is also worth noting that crops grown under a range of shade-tree species support substantially greater local diversity than do those grown under a single such species.

There is an even broader benefit from the massive shade trees that are an integral part of a rustic or polycultural cacao farm. They effectively sequester, or capture, carbon—acting as carbon "sinks" that shunt atmospheric carbon dioxide into fixed sites. That helps alleviate the buildup of the greenhouse gases in the atmosphere that are causing global climate change.

The "cocoa cycle" begins when growers clear forest vegetation to plant cacao seedlings. Later, when yields decline, they move on to new lands.

Historically, cacao itself has been a vagabond crop. Production levels have always been maintained largely by exploiting new forest frontiers worldwide. According to the botanist François Ruf of CIRAD, a French organization devoted to agricultural research for developing countries, the cycle begins as new forest is cleared. Seedlings are then planted that can take advantage of the cost-free nutrients in the soil of the newly cleared plot of land. With time, though, the cacao yields decline, until eventually the plot is abandoned. Then the "cocoa cycle" begins once again, on another patch of untouched forest.

In that way, as the worldwide craving for chocolate has grown, the unfettered forces of production have continued taking huge bites out of tropical forests around the globe. With no national guidelines—much less a global, or at least industrywide, policy—to address the hungry advance of cacao into natural forests, some of the very forests that have served as raw material for cacao production in the past 200 years will soon disappear.

It is true that, in global terms, cacao accounts for a small fraction of forest degradation and clearing at any given moment. Yet the impact of such production methods in particular areas, such as West Africa and the Indonesian island of Sulawesi, can be substantial, and where clearing targets forest that harbors endemic species, the threat to biodiversity can be great. Furthermore, if production continues to be concentrated in particular frontier regions, the crop becomes increasingly vulnerable to new fungal diseases. Geographical diversification can help maintain the supply, but eventually a long-term vision is needed.

Some large companies have accepted responsibility for taking that long view, and have begun to fund research on natural agents that could control some of the diseases that plague cacao trees. There is a growing realization that maintaining cacao as an environmentally and economically sustainable crop is inextricably linked with the well-being of the hundreds of thousands of small farmers who tend the crop—and hold the key to future supply. And for small growers, biological methods of controlling disease are far more affordable—and far safer—than the expensive, environmentally detrimental chemicals so often applied by the owners of monocultural plantations.

Along with the recognition of the importance of the small farmer, a consensus is emerging among ecologists, economists, experts in economic development, and industry-based investigators that agroforestry, employing a diverse shade canopy, is the cornerstone of sustainable cacao farming. In Brazil's cacao zones, recent planting schemes have been incorporating multiple species of shade trees, native forest species, and hardwoods or other economically valuable crops such as palms or bananas, all of which can increase the cacao farmer's income and diversify the farmer's product.

Certain enduring problems have relatively simple solutions. In Indonesia, for instance, the early harvest of the pods has reduced losses from a moth pest. Other initiatives are more complex. In Peru, treating the trees with certain plant-dwelling microorganisms, as well as with ecologically benign fungi that parasitize other fungi, has cut infestations of the witches'-broom fungus by 50 percent, and yields have increased by 20 percent (those programs, funded by Mars, Inc., of Hackettstown, New Jersey, draw on the resources

and expertise of the U.S. Department of Agriculture). Scientists at the Smithsonian Tropical Research Institute have begun to identify some fungal endophytes—species that grow within plant tissues—that when present in cacao leaves and fruits may serve as natural biological controls against other fungi, such as those that cause the devastating disease known as black pod. Private chocolate interests have sponsored projects that link grower groups with disease experts and are funding research whose findings will be published in scientific journals.

But the economic factors that affect cacao farmers are less easily controlled. Cacao is a poor farmer's crop, and the pluck and perseverance of the growers who migrate to remote areas to carve out a livelihood are rarely rewarded with fair prices. No matter how well they anticipate adversity, they are constantly buffeted by market fluctuations in the price of cacao beans, driven by forces far away from the farm. A good example is last fall's surge in world cacao prices to eighteen-year highs, about $2,500 per metric ton, caused in part by civil turmoil in Côte d'Ivoire. Yet at the same time in neighboring Ghana, where the government sets the price growers receive, farmers had to settle for just $763 a metric ton—70 percent less than the market rate.

Thus the fundamental issue of what the grower gets paid remains unsolved. Activists in the "fair trade" movement have convinced some of the major players in the chocolate industry that price has to cover the true costs of production by the small farmer and provide a living wage to the farm family. Several industry giants are now buying cacao at a higher-than-market price from associations of small growers; part of the money then goes toward community development and the implementation of sustainable production techniques. And several smaller but quite upscale companies are working directly with producers to showcase their cacao beans in certified organic chocolate products.

So the next time you order chocolate mousse, topped by a few shavings of bitter chocolate and a dab of whipped cream, think of it the way you might think of homemade strawberry jam, or hand-rolled sushi, or a top-flight French wine—something that's worth paying extra for. Chocolate, too, at least at the grower's end of the production chain, remains a cottage industry: the work of many hands, by people who have to pay their own bills. And then, because you truly enjoy it, savor their work. □

Mexican Indian woman is pictured as she prepares a chocolate-flavored drink, in this facsimile of a page from the Codex Tudela (1553).

Summer Flings

Firefly courtship, sex, and death

By Sara Lewis and James E. Lloyd

The fireflies, twinkling among leaves, / make the stars wonder.
—Rabindranath Tagore (1861–1941)

Bo Bartlett, *Firefly,* 1994

As light slips from the summer sky, an army of male fireflies awakens from its daytime slumber. One by one, the insects march up blades of grass, waiting until dusk to lift off like miniature helicopters into the night. Yet these fliers aren't bent on military conquest; their goal is simple evolutionary survival. The fireflies we study—bioluminescent members of the genus *Photinus*—devote every night of their short adult lives to courtship, first broadcasting their amorous intentions with flashing light signals, then seeking to mate with responding females.

Few insects are considered charismatic, but fireflies are a clear exception. All over the world their spectacular courtship displays have long delighted children and inspired poets. On long summer evenings throughout the United States countless children chase fireflies through fields and backyards. In Japan, where a broad respect for nature is both traditional and deeply felt, fireflies—*hotaru*—are particularly revered. School graduation ceremonies feature the song "Hotaru no Hikari," which means "fireflies' light," and many cities celebrate communal firefly watching with annual festivals known as *hotaru matsuri* ("fireflies' festival"). In the popular Japanese cartoon *Sailor Moon,* the heroine is Tomoe Hotaru, a name that means "firefly of earth." And in Japanese poetry the firefly serves as a metaphor for silent yet passionate love.

As biologists, the two of us still fall under the spell of fireflies. In particular, it is their single-minded focus on procreation that has inspired us, as students of the evolutionary process of sexual selection, to spend countless nights for the past several decades observing their drama of love and death. We, along with our colleagues, have been keen to learn what makes certain individual fireflies more likely than others to find mates and insure that their genes are passed on to future generations. And our observations, both in the wild and in the laboratory, have led to new insights into how fireflies (and other

species as well) play the game of evolutionary survival—how they live, love, and die.

Fireflies are not flies at all, but beetles, belonging to the family Lampyridae. To date, entomologists have formally described some 2,000 firefly species worldwide. The family includes some nonluminescent (and often diurnal) species that rely on pheromones to locate mates, as well as some species that merely glow rather than flash. In North America the flashing fireflies fall into three main genera: *Photinus, Photuris,* and *Pyractomena.*

To the uninitiated, the adults of the three genera look almost identical. Like all beetles, they have elytra, the hardened front wings that form a protective sheath above the hind wings; it is the latter that are used for flight. Most of the fireflies in the three genera have black elytra edged with yellow, and a shieldlike head covering, typically with red markings. Subtle morphological differences separate the genera; within each genus, entomologists distinguish species by differences in coloration, in the shape of male genitalia, and in flash behavior.

Fireflies themselves generally have no trouble determining whether another firefly belongs to their own species, or to their own sex for that matter. To do so, they rely solely on species-specific flash patterns—one or more short pulses of light. To iden-

tify males of their own species *Photinus* females key in on several flash characteristics, including pulse rate, duration, and the number of pulses in the overall flash pattern. *Photinus* males, in turn, usually focus on the length of the time delay before a female responds with a flash of her own.

By mimicking the signals of each sex with a penlight, you, too, can attract males and get responses from females. With one in hand, you can distinguish males from females by the size of the light-producing lantern on the underside of the abdomen. In the *Photinus* male, the lantern takes up the entire last two abdominal segments. In the female, the lantern is much smaller, restricted to the middle of the penultimate segment.

Fatal attraction: after luring a small Photinus *male firefly with false signals, the large* Photuris *female firefly devours him.*

However conspicuous it is, the adult stage of the firefly makes up only a small fraction of the life cycle. In North American fireflies the adult stage lasts at most a few weeks. The life cycle begins when the female lays her eggs in moist soil or moss. After about two weeks the eggs hatch, and minute, carnivorous larvae emerge. Firefly larvae live underground or beneath leaf litter, feeding on earthworms, snails, slugs, and soft-bodied insect larvae. In the northern United States fireflies probably spend between one and three years as larvae; farther south they can complete their development within a few months of hatching. Firefly larvae pupate in late spring within an igloo-shaped underground chamber. They emerge a few weeks later, having assumed their familiar adult form.

Once fireflies reach adulthood, the race for reproduction is on. *Photinus* fireflies devote their entire adult lives to reproduction; most of them do not eat after they become adults. Triggered by dusk's fading daylight, male fireflies lift off into the air and begin their courtship. The roving males fly slowly, between three and six feet above the grass, advertising their availability with a flash pattern of one, two, or several short light pulses, repeated at regular intervals [*see diagram at bottom of opposite page*].

Females, meanwhile, remain perched low in the vegetation; in *Photinus* species the females rarely fly. Females respond to male advertisements with a single pulse (or in a few species, multiple pulses). After a male sees a female response, he drops out of the air to continue his search "on foot." The flash dialogues continue, often lasting more than an hour, and the ongoing conversation acts as a magnet for other males. By the time courtship flight ends, several males can often be found scrambling up and down blades of grass, searching for the stationary female.

Biologists have long pondered how fireflies generate their precisely timed flashes. Work done recently by an interdisciplinary team of cell biologists, physiologists, and ecologists from Tufts University and Harvard Medical School has provided a key piece to the puzzle.

In fireflies light is produced in a chemical reaction, which can occur only in the presence of oxygen, between the compound luciferin and the enzyme luciferase. In the firefly lantern, thousands of specialized cells called photocytes sequester luciferin and luciferase deep within their interiors. Densely packed around the photocyte margins are mitochondria, the oxygen-consuming power plants that occur in nearly all eukaryotic cells. The team found that the firefly nervous system does not control the photocytes directly; instead, the flash-triggering nerve impulse arrives in the lantern at nonluminescent cells adjacent to the photocytes.

The nerve signals trigger the production of nitric oxide (NO). That discovery offered significant insight into firefly flash control. The NO molecule is a ubiquitous intercellular messenger that has an astonishing array of biological functions. In people, it controls blood pressure, regulates penile erection, and mediates learning and memory. In the firefly lantern, NO switches the flash on by temporarily shutting down the oxygen consumption of the photocyte's mitochondria. Oxygen can then diffuse farther into the interior of the photocyte, where it triggers the light-producing reaction between luciferin and luciferase. The flash turns off as NO quickly degrades and mitochondrial oxygen consumption is restored.

A maturing firefly larva attacks a hapless slug.

The highly visible courtship signals among fireflies, and their short adult lifespans, make fireflies particularly amenable to studies of sexual selection. Darwin coined the term "sexual selection" to refer to differences among a species' males and how successful they are at gaining access to females. According to Darwin, the reproductive advantage goes to males that can prevail over rivals or that can more effectively attract females. Later biologists have realized that mere copulation is not sufficient to ensure a male's reproductive success; in many animals females mate with multiple males, and both male sperm competition and female sperm choice can create differences among mating males in the number of offspring they sire. In fireflies, a male's reproductive success depends not only on his courtship ability, but also on his postcopulatory ability to fertilize his mate's eggs.

Sexual selection in fireflies begins during courtship. Recent studies show that female *Photinus* fireflies discriminate between potential mates by evaluating their flash patterns. The flash pattern of *Photinus consimilis* males is made up of four to twelve rapid pulses. Marc A. Branham, now of Ohio State University in Columbus, and Michael D. Greenfield of the University of Kansas in Lawrence found that among *P. consimilis* fireflies, the faster the male's pulse rate, the more frequently the female responds. Yet males of many other *Photinus* species emit singly pulsed courtship flash patterns. For example, Christopher K. Cratsley, now at Fitchburg State College in Massachusetts, found that in *P. ignitus,* the longer the male's courtship flashes, the more likely the female is to respond. As one might expect, getting a female to respond is crucial to a male's mating success. Field studies show that firefly males that elicit more female responses during courtship are most likely to succeed in mating.

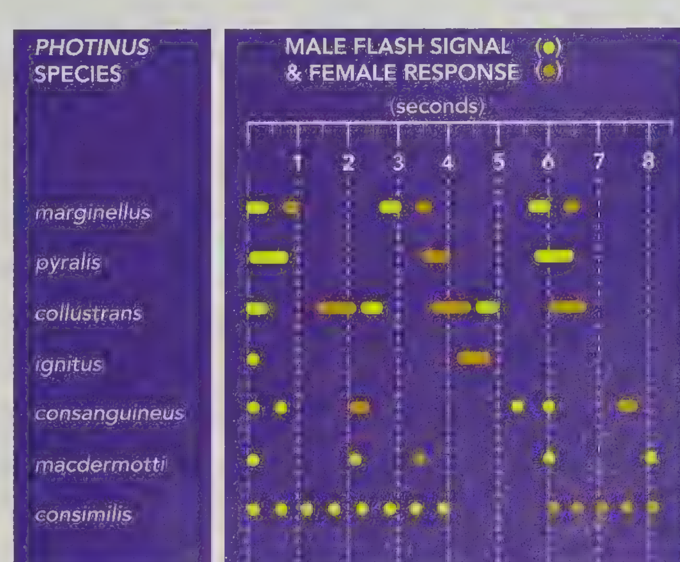
The light show is over when copulation begins. In *Photinus* fireflies, copulations generally last several hours, a practice that limits both males and females to a single mating each night. One reason for such prolonged mating is that the males are busy transferring a "nuptial gift" to their mates. The nuptial gift of the firefly is an elegant, spirally coiled sperm-containing package called a spermatophore [*see photomicrograph on next page*].

Because *Photinus* fireflies do not feed as adults, male nuptial gifts may be particularly important as supplementary nourishment for the female's eggs. Radiotracer studies found proteins derived from the spermatophore in the developing eggs. Females, too, may benefit from male nuptial gifts: *Photinus* females that have mated with three different males can produce nearly twice as many offspring in their lifetimes as can females with only one mate. Cratsley's studies also show that the longer the duration of the courtship flash of *P. ignitus* males, the bigger the male's spermatophore. Hence male courtship flashes might signal to females the size of the male's intended nuptial gift. If so, the female preference for longer male flashes in this species should allow her to produce more offspring.

But even after his gift is accepted, the male's quest to propagate his genes has not necessarily succeeded. In most *Photinus* species each female typically mates with many different males, yet the mating males are not all equally likely to fertilize her eggs. Only the females of the species *Photinus collustrans,* studied by Steven R. Wing at the University of Florida in Gainesville, are known to mate just once before death. In most *Photinus* species the sperm of several males compete.

A glimpse into the male firefly's struggle for paternity comes from doctoral work done by Jennifer Rooney at Tufts. She discovered that males providing larger spermatophores also sired a greater fraction of a female's offspring. But such success is not without cost; a male's spermatophore size declines steadily with each additional mating.

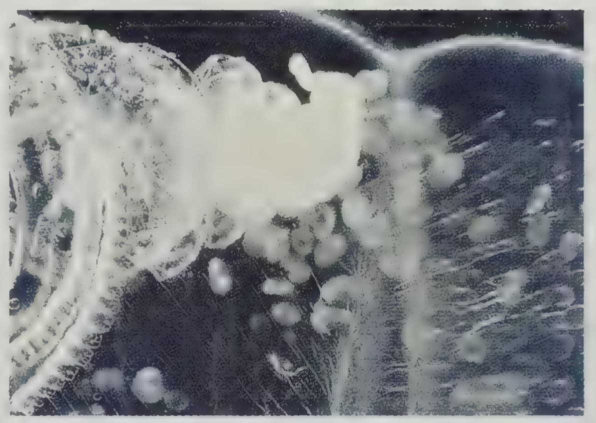
The traditional theory of sexual selection holds that males, whose gametes are relatively small and



energetically inexpensive to produce, will mate as often as opportunity allows. Females, in contrast, whose gametes are large and costly, will be much more selective than the males about their mates. For at least some of the *Photinus* firefly mating season, that pattern seems to hold. Early on, males compete for access to females, whereas females respond to flashes only if they're impressed.

But because *Photinus* fireflies don't eat once they become adults, the males can produce only a limited number of spermatophores in their lifetimes. As the availability of spermatophores dwindles, the males become increasingly selective about which female they mate.

Firefly flashes may be a natural form of poetry, but they are also highly visible signals that make courtship a risky business. Flashes are readily intercepted by predators. As protection, *Photinus* species and some other fireflies contain noxious, extremely bitter compounds known as lucibufagins, which deter many potential predators such as spiders, primarily, as well as birds, lizards, and ants.



Firefly spermatophore delivers both the sperm of the male (here still bundled into rings) and sustenance for the eggs of the female. The image shown is magnified approximately 100 diameters.

But not even noxious chemicals can protect *Photinus* fireflies from their archenemies, the larger, quicker *Photuris* fireflies. Female *Photuris* fireflies are leading ladies among the insect world's infamous troupe of femmes fatales. *Photuris* females are highly specialized predators that spy on *Photinus* courtships, then imitate the flash responses normally given by *Photinus* females. Those false signals lure unsuspecting *Photinus* males into the clutches (and guts) of their predators. The *Photuris* female is a voracious predator that can devour several *Photinus* fireflies each night. And, in the process, she gets much more than just a nutritious meal. The ecologist Thomas Eisner and the chemist Jerrold Meinwald, both of Cornell University, discovered that *Photuris* females can co-opt the bitter chemical deterrents produced by their *Photinus* prey to deter their own predators.

In addition to such natural hazards, human activities pose problems for fireflies. Pesticide use takes a toll, and urban sprawl increasingly threatens the open fields and woodlands inhabited by various firefly species. Fireflies tend to be highly site-specific, gathering and mating year after year in the same spot. If a population's breeding site is disturbed, migration to nearby areas is unlikely, and local extinction is almost certain.

Bounty hunters, too, may have been contributing to declining firefly populations. For about forty years the Sigma-Aldrich Corporation in St. Louis, seeking luciferin and luciferase, sponsored a firefly-collecting club. The company paid a network of collectors nationwide a penny a firefly (with quantity bonuses that total $600 for 200,000 fireflies). Millions were collected. Although a few firefly species might be abundant enough to support such harvesting, many less-abundant species (and species are collected indiscriminately) could readily be snuffed out. Fortunately, there is no longer any reason to collect fireflies from the wild. Synthetic luciferin has long been available, and the firefly luciferase gene has been cloned. Sigma-Aldrich ended the collecting club a few years ago.

Fireflies have been at risk even in Japan, where they are so revered. Japanese firefly larvae live in water, and by the 1960s industrial pollution and residential development had so damaged the rivers that larval survival rates had dropped precipitously. Many communities responded by setting up river restoration projects aimed at reviving local firefly populations. The projects were largely successful and, combined with citizen efforts to rear firefly eggs into healthy larvae that could be released into the rivers, they have transformed fireflies into a national symbol for environmental conservation in Japan.

"Photopollution" too endangers fireflies. The insects depend on low-light backgrounds for their courtship signals to be seen. But bright streetlights and floodlights may overwhelm firefly courtship flashes, and so reduce breeding populations. Yet simple remedies, such as shades and timers, can minimize such disruptions.

As biologists continue to learn about firefly behavior, this knowledge—how courtship signals are generated, how nuptial gifts affect mating behavior, how a male's success at mating is related to his success at fertilizing eggs—may help biologists clarify and strengthen the understanding of life in general. And we hope that the enhanced understanding of firefly ecology will help ensure that fireflies continue to thrive on Earth, to inspire wonder in our children—and in the stars. □

During mating a Photinus *male firefly (lower beetle) donates a nuptial gift to a female.*

Valley High

A California forest harbors cobra plants and other treats for plant lovers willing to get their feet wet.

By Robert H. Mohlenbrock

Oxeye daisies, originally introduced from Europe, bloom on private land along Butterfly Creek.

When I first read about Butterfly Valley in an issue of *Fremontia,* the journal of the California Native Plant Society, I knew I had to see it. The valley's boggy areas, seeps, and ponderosa-pine forests are home to more than 500 kinds of plants. Among them are large concentrations of the insect-eating cobra plant (whose hoodlike leaf bears what looks like a forked tongue); four other species of insectivorous plants (two sundews and two bladderworts); and twelve kinds of wild orchids. Butterfly Valley, through which runs Butterfly Creek, lies in the northern Sierra Nevada mountains and is named for its overall shape, discernible when viewed from mountain heights. A 500-acre portion of the valley, part of California's Plumas National Forest, is designated a Botanical Area, which protects it from wildflower picking and commercial logging.

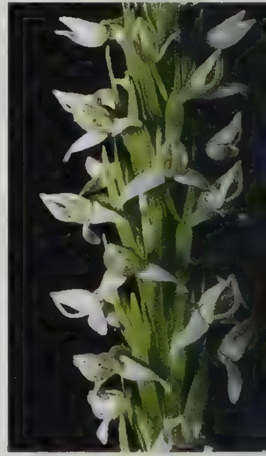
Green-leaf manzanita

On a pleasant morning in August my wife Beverly and I set out on California Highway 70, which crosses east-west through the national forest. Roughly midway, near the community of Keddie, we found the unposted turnoff onto County Road 417, a narrow asphalt road that turns to gravel after about a mile and a half. Continuing another mile on the gravel we took a left turn onto a Forest Service road that led southward through the botanical area. At first all we saw were woods dominated by ponderosa and sugar pines. Then we sighted our first cobra plants, growing in standing water along with sedges, rushes, and other wetland plants. This boggy habitat, best termed a fen because it is fed by water seepage from the bottom of the adjacent hillside, parallels the road for a hundred feet or so.

Less than a quarter-mile farther down the road, we came to Sweetwater Marsh, ten acres of open land surrounded by a narrow border of alders. The continuous cover of vegetation obscures a very wet terrain, which I deemed it best not to enter.

A short distance past Sweetwater Marsh we came to Pond Reservoir, the deepest body of water in the botanical area, thanks to a dam constructed there around the turn of the twentieth century. This pond and its muddy borders support additional communities of plants. I noticed that most of the aquatic species I could identify are also familiar in the Midwest and eastern United States. As a matter of fact, aquatic plants generally do have broad geographical ranges, which botanists attribute to the relative uniformity of their watery environment, compared with the variability of soil and other conditions on dry land.

Proceeding along the road to the south end of the botanical area, we came upon a moist, heavily shaded area known as Fern Glen. True to its name, it was home to an assortment of gorgeous ferns, which grew amidst numerous wildflowers. Exploring on foot, we also found a small zone dominated by bear grass, a huge plant with long, narrow, grasslike leaves that is actually a member of the lily



White-flowered bog orchid

family. It produces a large spike of white flowers in August.

From there we continued south and east, and the road eventually turned into the paved Blackhawk Creek Road and connected directly with California Highway 70 (the Forest Service prefers visitors to enter as well as leave the botanical area using this route). On the way the road crosses Big Blackhawk Creek and parallels Little Blackhawk Creek, which like Butterfly Creek are lined with dense thickets of willows, alders, and red osier dogwoods. The waters of all three eventually travel southward down the Feather River, all the way to San Francisco.

HABITATS

Mixed conifer forest Ponderosa pine, locally often called yellow pine, grows with other tall conifers—sugar pine, white fir, Douglas fir, and incense cedar. Deciduous trees, such as California black oak, Pacific dogwood, and big-leaf maple, are much less common. The most plentiful shrubs are green-leaf manzanita (with thick, leathery leaves and a red trunk) and white-leaf manzanita (with its pale leaves). Two wildflowers that are striking because of their white-striped leaves are giant rattlesnake plantain and white-veined wintergreen. Other species include purple fritillary, Sierra iris, crimson columbine, slim larkspur, two kinds of lupines, mosquito-bills, and woolly mule ears.

Cobra plant fen The cobra plant *(Darlingtonia californica,* also known as California pitcher plant) lives mostly among sedges and rushes. There are also round-leaved sundews, some shrubs of Labrador tea and bog bilberry, and various colorful wildflowers, including four members of the lily family—bog asphodel, western tofieldia, beavertail grass, and *Hastingsia alba.* Some other wildflowers are white-flowered bog orchid, California grass-of-Parnassus, Sierra gentian, Plumas alpine aster, western sneezeweed, and the highly toxic western water hemlock.

The cobra plant, or California pitcher plant, traps and digests insects.

Marsh The vegetation in Sweetwater Marsh is made up mainly of grasses, sedges, and rushes, but here also grow cobra plants, two sundews, including the round-leaved one common in the fen, and various wildflowers—among them wild hyacinth, bog saxifrage, yellow monkey flower, Parish's yampah, sheep parsnip, and a species of Saint-John's-wort.

Pond Standing water in Pond Reservoir harbors two bladderworts (which trap small aquatic insects), as well as arrowhead, water plantain, water smartweed, blister sedge, marsh cinquefoil, two buttercups, water-shield, a pondweed, watercress, and the tiny water starwort. Common in the surrounding mudflats are a variety of sedges and rushes, northern bog violet, water purslane, and primrose monkey flower.

Glen Sierra water fern, lady fern, and California grape fern grow in Fern Glen beneath a canopy mostly of ponderosa pine. One attractive shrub is the Sierra currant. Wildflowers include wild ginger, two species of woodland-stars, Mt. Lassen fleabane, broad-leaved aster, red larkspur, false Solomon's-seal, fawn lily, twisted-stalk, and Kelley's lily.

Glade Growing with the bear grass in Beargrass Glade are Washington lily, Oregon white-topped aster, pearly everlasting (whose white, paperlike flower heads persist for weeks), and a shrub known as Sierra laurel.

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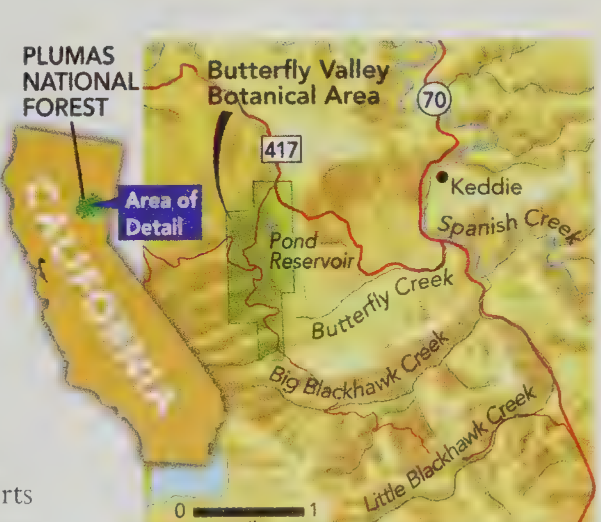
www.fs.fed.us/r5/plumas/



The Mismeasure of Science

In his last book Stephen Jay Gould argues it is a mistake to judge the "magisterium" of science for its failure to engage ethical questions.

By Michael Ruse

My most vivid memories of Stephen Jay Gould date back to December 1981. The place was Little Rock, Arkansas, and the scene was a courtroom where evolution was under attack by so-called scientific creationists. The two-year interregnum in Bill Clinton's five-term gubernatorial leadership was at its midpoint, and had left the state with a governor whose surprise at gaining office was matched only by his inadequacy for the post. The creationists had managed to get the Arkansas house and senate to pass a bill mandating the teaching of both evolution and Genesis in publicly funded school biology classes, and the governor had signed it into law. The American Civil Liberties Union (ACLU) immediately sprang into action to have the law declared unconstitutional, arguing an unwarranted breach of the separation of church and state. Steve and I served as expert witnesses, testifying that evolution is genuine science and that creationism is old-time religion.

In the end the ACLU won the case handily, but at first things were tense. The state's attorney-general hammered away at the pro-evolution witnesses and, as happens in these cases, a certain amount of mud was thrown, and some of it stuck. But by the end of the third day it was clear that we were starting to come out on top. The Arkansas schoolteachers proved to be the most impressive witnesses of all, simply by demonstrating why they could never teach Genesis as biology, no matter what their religious beliefs. (As I remember the episode, all of them were Christians.)

That evening all the ACLU supporters—lawyers, expert witnesses, hangers-on—were relaxing in one of the superb restaurants of Little Rock. A lot of wine was drunk. Then the singing began—instigated by some rather angelic-looking law clerk. The only songs most of us knew in common were the Christian hymns of our childhood, so that was the way we went. And I'll never forget Steve Gould—Harvard professor, secular Jew, eminent evolutionist—belting out "Amazing Grace," especially those lines about being in heaven and praising God's grace for the first ten thousand years, at which point: "We've no less days to sing God's praise / Than when we'd first begun."

The Hedgehog, the Fox, and the Magister's Pox: Mending the Gap between Science and the Humanities
by Stephen Jay Gould
Harmony Books, 2003; $25.95

For me those recollections epitomize what Stephen Jay Gould was all about: First, that he was there at all—many other prominent figures, beginning with Carl Sagan, had been too busy to take time out to go to the South and fight the creationists. But Steve felt it was his public duty, and he never gave it another thought. Second, that he could fight a good fight. Guess who had just roughed up the lawyers for the state? Guess who had just given them a science lesson that they must remember to this day? Third, that he acted as part of a community, willing to share in the group's tensions as well as its triumphs. And fourth, that he could, and would, sing. Steve was well-known for his love of oratorio, and appreciated its power to move people's hearts.

Personally, Steve had no time for creationism, or for evangelical religion generally, but he understood why others were attracted to it. He was a genius, tremendously creative, and, to the regret of those of us who knew him, terribly arrogant at times. Yet ironically, one of his strengths lay in his capacity to empathize with regular folk, because he was regular folk—he was a born and bred New Yorker whose daddy had been a court reporter, who loved baseball, whose aged relatives could never understand why he hadn't become a "real" doctor. Those things stayed with him.

Stephen Jay Gould is gone now. Those of us who knew him, and many who didn't, are pained by the thought that he died too young, and yet inspired by the example of his personal courage: twenty years ago (shortly after the Arkansas trial), he fought back a particularly vile form of cancer and then continued writing, teaching, and lecturing for another two decades.

Now we have Gould's final book on science, published posthumously. The title—*The Hedgehog, The Fox, and the Magister's Pox: Mending the Gap between Science and the Humanities*—is a bit misleading. Frankly, I am still unsure how "the magister's pox" fits in. But "the hedgehog" and "the fox," Gould tells us, refer to some lines attributed to the seventh-century B.C. Greek poet Archilochus: "The fox devises many strategies; the hedgehog knows one great and effective strategy." The sentiment might lead you to think Gould chose his title to differentiate between science on the one hand (perhaps foxlike in its many ways of going at things) and the humanities on the other (hedgehoglike in sticking to one theme or topic). But that reading doesn't hold up for long: foxlike behavior and hedgehoglike behavior, Gould says later on, characterize both fields, and neither approach can be considered entirely right or entirely wrong.

Not that the distinction matters terribly much. In several passages throughout the book Gould seems to remember the hedgehog-fox theme he started with, but only somewhat guiltily, at the ends of chapters. No doubt much of this textual confusion would have been addressed in a final rewriting, but Gould died before there was time for that. Because the publisher has seen fit to issue the book anyway, the text as it now stands demands a more interpretative reading than one would ordinarily expect to accord it.

Recognizing this practicality and its pitfalls, I see Gould posing and tackling three interrelated questions: First, is there a divide between science and the humanities? If there is, what is its nature and how did it come about? Finally, what, if anything, should people do about it?

The Natural Sciences in the Presence of Philosophy, engraving attributed to Hans Holbein the Younger, 1497–1543

On the first question Gould is surprisingly ambivalent. He properly focuses on the essay "The Two Cultures," written in the late 1950s by the English novelist and physicist C.P. Snow. The scientists and the humanists, Snow argued, are practitioners of the two distinct cultures, and they don't talk to each other—to the particular detriment of the humanities. The average scholar of a subject such as English literature knows nothing of quantum mechanics, and the world and its governance are the poorer for it.

Snow was attacked—brutally—by British humanists when his essay was published. But Gould, though uncomfortable with some of Snow's more venomous critics, is by no means content to toe the "scientist" party line in defending Snow. Snow's complaint that humanists are ignorant of basic science, Gould charges, was grossly exaggerated, overgeneralized to the entire Western world on the basis of the highly limited form of education Snow was familiar with in mid-twentieth-century England. (I can personally attest, though, that Snow was right about England: one began specializing at the age of fifteen, effectively ignoring everything that was not related to one's chosen field.)

More important, Gould seems reluctant to embrace Snow's contention that such a divide exists in England,

or that it goes very deep. And even if it does, Gould acknowledges, the English cannot be held responsible for single-handedly keeping science separate from the humanities. The so-called science wars between scientists and humanists in the past decade demonstrate that the divide exists in North America as well.

On one side of those wars are scientists who remain convinced that they are objectively mapping reality—in the immortal words of Howard Cosell, they "tell it like it is." Their patron saint is Sir Karl Popper, the Austrian-born English philosopher who spoke of science as "knowledge without a knower," meaning that it rises above the individual and his or her culture. On the other side of the science wars are historians and sociologists of science and various others, particularly in departments of English and cultural studies, who think that science is as subjective as religion or philosophy. Their patron saint is the French critic and philosopher Michel Foucault, who believed that true objectivity is as untenable in science as it is anywhere else.

In that rancorous debate Gould the scientist seems to be at war with Gould the historian. On the one hand, he clearly thought that science makes it possible for people to discover truths about reality. He would have claimed that punctuated equilibrium—a theory he developed in 1972 with the evolutionary biologist Niles Eldredge of the American Museum of Natural History, to explain the jerky nature of the fossil record—genuinely says something about the real world. On the other hand, Gould the historian—for instance, in his account of the sorry history of I.Q. testing, in his book *The Mismeasure of Man*—was at the forefront of those showing that people can be as creative about finding "objective" support for their positions as their pernicious ideology demands.

James Barsness, *The World All Around*, 1998

Gould's second question in *The Hedgehog, the Fox, and the Magister's Pox* is, What is the divide between science and the humanities all about, and how did it come to be? Given his insightful earlier work, I do not find him as helpful on that topic in this book as one might have hoped. As I understand it from my reading of his 1999 book *Rocks of Ages,* his position is that, because science and the humanities deal with different kinds of issues and topics, neither their methodologies nor their conclusions can be the same.

Take the paired concepts of science and morality, or science and religion. Morality and religion—two concepts Gould often runs together—seem to belong to one domain and science to another (Gould calls these domains *Magisteria*). They are two world systems that cannot intercept each other, both because they ask different questions of different things and because the answers appropriate to one system are not the ones appropriate to the other. Although they can exist together (and, one hopes, in harmony) they cannot, by their nature, conflict.

Several times in *The Hedgehog, the Fox, and the Magister's Pox* Gould makes approving reference to the philosopher David Hume's division of things into matters of fact and matters of obligation: "I have this," as opposed to, "It is right and proper that I have this." Gould also agrees with Hume's assertion that, logically, there is no way to get from one to the other. He goes on to argue (though with less force than he does in *Rocks of Ages*) that science answers factual questions, whereas religion deals with matters of feeling, sentiment, and obligation. Again, the two cannot conflict. I think this is Gould's position, but I'm not sure it's

as conciliatory toward religious points of view as Gould, with his avowed ecumenical spirit, might have hoped.

Certainly history suggests that conflict between science and religion in particular, and science and the humanities in general, is nothing new. The breakdown began during and immediately after the scientific revolution, in the sixteenth and early seventeenth centuries. I suspect, however, that much of the present divide can be traced to the epochal nineteenth-century battles between scientists and humanists, the latter often associated with powerful religious groups. A good example is the debate that erupted soon after the publication of *Origin of Species* between Thomas Henry Huxley, Darwin's bulldog, and Samuel Wilberforce, Bishop of Oxford. Such conflicts generated great tension on both sides of the science-humanities divide: to a large extent, we are still living with the legacy of the Huxley-Wilberforce debate, and of similar hostile encounters. Would that I could sit down for an evening with Gould and argue the issue.

If Gould is less than forthcoming on the first two questions, he is eloquent and articulate about how people ought to respond to the divide. Science and the humanities will always remain separate, he says, because they belong to separate *Magisteria,* and any attempt to combine them is doomed to fail. His motto is: Separate but Equal, with Respect. But what about those who don't agree with this opinion? Gould concludes his book with an extensive, two-chapter critique of the position taken by his colleague at Harvard, the entomologist and sociobiologist Edward O. Wilson.

Wilson wants to combine everything—science, politics, religion, ethics, you name it—within one massive framework. To capture his vision, Wilson borrows a word from the nineteenth-century English historian and philosopher of science, William Whewell (pronounced "Hule"). In speaking of Newtonian mechanics, Whewell praised it for bringing so much under so few hypotheses, and spoke of it as a "consilience of inductions." Wilson, too, wants a consilience, not just of all knowledge but especially of all knowledge about humans. He wants it all brought under, and explained by, evolution, particularly the part of evolution that pertains to brain science. For him, Hume's distinction between *is* and *ought* is something to be brushed away as irrelevant. What people ought to do is no more and no less than what our brains tell us, and what our brains tell us is what our genes, as naturally selected, dictate.

To Gould, that conclusion is anathema. It is false as science, fallacious as philosophy, and foolish as religion. Life is more than biology. Right and wrong, love and hate, beauty and ugliness, happiness and misery, and so much more may owe their existence to genes, but they also transcend them. To adopt Gould's most famous metaphor (referring in its literal sense to the triangular, often ornamented space on the exterior curve of an arch, sometimes seen atop columns in medieval churches), such emotions and concepts are, biologically speaking, "spandrels," things that seem to have a purpose but do not. As Gould argued at length in his 2002 book *The Structure of Evolutionary Theory,* culture in some sense takes off on its own, and to pretend otherwise is to commit the sin (just about the greatest sin, in Gould's book) of reductionism.

As Gould acknowledges in a lengthy footnote, he and Wilson were at odds for many years. So in a way, it is a little unfortunate, and somewhat petty, that Gould should have gone out with yet one more diatribe against Wilson. But in another way, that's not such a bad thing. As Gould stresses, the differences are intellectual, not personal. At stake is the choice—an important choice—between two quite different visions of the way people think and, in consequence, of the direction research should take. Gould airs the two visions and once again defends his own stance—on balance, an excellent way to finish off a glorious career.

I confess that my own inclinations are with Wilson. Science really does matter; and it matters to everything, not excepting emotions and concepts, the most significant of human aspects and activities. Without going to the extreme of embracing the position of a philosopher such as Daniel C. Dennett—who thinks that once you know all about the brain, you know all about the mind—I just do not see how one can think seriously about the mind without paying at least some attention to the brain, to the physical. And that includes asking biological questions about how and why natural selection gave rise to the human brain.

Gould the scientist would argue that science says something about reality; but Gould the historian would say that people can find "objective" support for whatever their ideologies demand.

The paradox is that, in major respects, Gould seems to agree with this position. He writes movingly of his older son, who is autistic, and about what a relief it is for parents to find that the cause of their child's affliction is biological, not bad parenting. At some level, Gould allows that biology does something important with the mind, and that if biology is not working properly, the mind does not work properly. The question is: How much further would Gould have been prepared to go?

Even though, as I mentioned, my inclinations are with Wilson, I think Gould is right in staying onside with

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(Continued from page 55)

Hume—I think one is always right in staying onside with Hume!—and arguing that Wilson is mistaken in claiming that ethics is simply a consequence of biology. At least Gould is right in maintaining that biology does not justify ethics—or, more pointedly, ethical lapses. What has evolved is not necessarily what is right and good. As Katharine Hepburn says to Humphrey Bogart in the movie *The African Queen:* "Nature, Mr. Allnut, is what we were put in this world to rise above."

So I find myself attracted to a position somewhere between Gould's and Wilson's: Wilson is right in thinking that biology can explain the origin and continued existence of ethics. Gould is right in thinking that biology does not justify ethics. And both are wrong in thinking that there is nothing more to be said on the matter. My philosophical instinct accords with Hume's: there can be no ultimate justification, whether it is provided (Wilson-style) by evolution or (Gould-style) by something other than evolution. Ethics just is.

By this point both Gould and Wilson would be after my hide, so this is a good point to draw to a close. *The Hedgehog, the Fox, and the Magister's Pox* is not one of Gould's greatest books. In science, that honor belongs to *Ontogeny and Phylogeny.* Among essay collections, I would still opt for one of Gould's first books, *Ever Since Darwin.* Of his monographs, *Wonderful Life* is way ahead of the others, and for me wins the prize as the best book overall. But in everything Stephen Jay Gould wrote there was always an abundance—to read, to reflect on, to learn from. I mourn his passing. I give thanks for his life. And I rejoice in how he enriched all of our lives.

Michael Ruse is a professor of philosophy at Florida State University. His most recent book is Darwin and Design: Does Evolution Have a Purpose?

BOOKSHELF

By Laurence A. Marschall

How the Cows Turned Mad
by Maxime Schwartz
University of California Press, 2003; $24.95

English farmers first sounded the alarm in April 1985, when otherwise healthy cattle started acting edgy, showing random fear and aggression, and kicking their handlers. The afflicted animals also wavered as they walked, then lost their ability to stand, to lift their heads, and, eventually, to breathe. Postmortem inspection of their brains exposed a tangle of lesions that had turned once-solid gray matter into a spongelike mass. Bovine spongiform encephalopathy,

A caricature of cowpox doing battle with the medical profession, glazed ceramic, c. 1800

or BSE, was its official name, but to a frightened, beef-loving public it became "mad cow disease."

The threat of mad cow disease, however, goes deeper than its monstrous effects on livestock or its economic impact on farmers. About a decade after the first cows went mad, ten cases of a new form of the degenerative brain disorder known as Creutzfeldt-Jakob disease (CJD) turned up in the U.K. CJD had been an extremely rare disease among people aged forty to sixty, but the average age of these newest victims was twenty-nine, and autopsies of their brains revealed lesions similar to the ones in diseased cattle. Just over a hundred deaths were reported from the new variant of CJD by 2001, and the evidence clearly suggests that the most likely cause is the consumption of beef.

Maxime Schwartz, a molecular biologist and now a professor at the Pasteur Institute in Paris (which he headed for a decade, from 1988 until 1999), has written a lucid and gripping account of these events in the context of the latest scientific research. "The Disease," as he prefers to call it, is actually one of several maladies similar in both cause and effect. In the mid-1700s, when it was first recognized in sheep, The Disease was called scrapie, because suffering animals tended to rub their skins raw. By the 1900s scrapie was recognized as infectious, but unlike viral or bacterial diseases, it seemed to produce neither a fever nor an immune-system response. Moreover, healthy sheep inoculated with tissue from animals with scrapie took years to develop symptoms, far longer than for any other known infection.

In the 1950s a similar disease was recognized in people: kuru, a wasting of the brain found among the Fore people of New Guinea, appeared to be transmitted by their traditional habit of eating deceased (and diseased) family members. Like scrapie, it was slow to manifest itself, and also like scrapie, it led to no immune response. Its symptoms resembled those of Creutzfeldt-Jakob disease, but since no CJD sufferers were ritual cannibals, the connection between kuru and CJD was unclear.

Around the time the mad cows first staggered onto the scene, Stanley

Prusiner, a microbiologist at the University of California, San Francisco, suggested that both diseases were caused by a new kind of infectious agent that was neither a virus nor a bacterium. He named it a "prion," and identified it with a nondescript protein that normally occurs in many mammals, including people. Although prion molecules do not incorporate DNA, and thus cannot reproduce by conventional means, mutant forms do have a primitive ability to induce identical imperfections in healthy prions. Schwartz calls it the molecular "kiss of death." The process leads to a growing accumulation of bad prions that eventually destroy nerve cells in the brain. At first Prusiner's idea was controversial, but biologists have gradually come to accept it, and in 1997 Prusiner won a Nobel Prize for his work.

Thanks to vigorous public-health measures, including a ban on feeding animal tissue to livestock, mad cow disease seems to be on the wane. But prion disease remains frightening. Because it takes years for its symptons to develop, Schwartz cautions, the extent of cow-induced infection in people may not be known for another generation. Nor can we assume that BSE is the ultimate prion infection. Suppose "The Disease" morphs into a form that causes few symptoms in animals but moves much more readily than BSE from livestock to people? Then even Ronald McDonald might decide to become a vegetarian.

An Obsession with Butterflies: Our Long Love Affair with a Singular Insect
by Sharman Apt Russell
Perseus Publishing, 2003; $24.00

Butterflies, as nature writer Sharman Russell aptly observes, can be practically invisible at times, as though they inhabited a separate dimension; they flutter among us in full

view, and yet we scarcely notice them. She's right. I can distinguish a robin from a blue jay, a crow from a sparrow (and even, like Hamlet, "a hawk from a handsaw"), but I couldn't identify a single one of the ninety-three common species of butterflies Russell lists in the preface to this slender collection of essays. If my experience is any measure, many people probably regard butterflies as elements of the landscape, flashes of color no more distinctive than a dropping leaf or a flower petal floating on the wind.

From a butterfly's point of view, that is all to the good; a typical member of the order Lepidoptera devotes its brief life to being neither noticed nor eaten before it mates and produces its young. To Russell, however, that is a pity. An acute awareness of butterflies, which she developed after a brief encounter with a swallowtail in New Mexico, has convinced her that butterflies add a luminous dimension to one's life.

Obsessive butterfly collectors, the subject of her title essay, can take this pleasure to extremes. Take Lord Walter Rothschild, a quintessential Victorian eccentric: Over a lifetime of collecting, with the help of professional collectors, he amassed 2.25 million specimens. Rothschild's collection resides in the Natural History Museum in London, along with six million other butterflies and moths collectors have added over the years. Or take Vladimir Nabokov, the most famous of the bunch: not only did he insert allusions to butterflies throughout his fiction, he also wrote twenty-two scientific papers on members of the order, and discovered several new species.

Gregory Halili, *Butterfly Collection (Fabrics) #2*, 2002

Russell's obsession is more benign: she collects facts and stories about butterflies and then writes about them with grace and good humor. Did you know that most butterflies have taste buds on their feet, and "eyes"—light-sensitive cells—on their genitalia? That the caterpillars of the Panamanian metalmark butterfly secrete an intoxicating fluid they exchange with ants in return for protection from wasps? Can you appreciate the endurance of the male and female queen butterflies, which are locked in coitus for as long as eight hours at a time (a sizable fraction of their active lifespan)? Does it seem amazing that, during a migration of snout butterflies in September 1921, many millions crossed a 250-mile-long corridor between San Marcos, Texas, and the Rio Grande River each minute, for eighteen solid days—tens of billions of insects in all?

There are lessons to be learned from this assortment of lepidopteran lore. Many of the oddities of butterfly life are Darwinian adaptations to a harsh world in which birds and insects are looking for a handy afternoon snack. Colorful bands on a butterfly's wing provide camouflage among leaves and flowers, of course, but they can also divert a predator's eye toward the butterfly's tail, where a little bite won't matter as much as a chomp on the head. Some markings mimic the eyes of creatures frightening to predators; other markings, common among "sweet-tasting" species, mimic the patterns of unrelated butterflies that birds know to be "bitter."

Overall, however, Russell's lyrical stories appeal to our aesthetic, rather than to our moral, sensibilities. We don't ask what lessons we learn from a Mozart concerto; nor should we ask more of butterflies. Better to enjoy them, not for their utility, but for their quirkiness and their beauty. She quotes Miriam Rothschild, niece of the great Victorian collector, who viewed them, not with the eyes of a professional entomologist (which she was) but as "dream flowers—childhood dreams—which have broken loose from their stalks and escaped into the sunshine."

Oxygen: The Molecule that Made the World
by Nick Lane
Oxford University Press, 2003; $35.00

Our Earth is an odd place. No other planet in the solar system has so much oxygen in its atmosphere. Although oxygen is a rela-

tively common element in the universe, its atoms are so reactive that they never float around by themselves. Pump an atmosphere full of monatomic oxygen, chemists will tell you, and every unattached oxygen atom will immediately rush off to find a mate, combining with iron to form rust, with carbon to form carbon dioxide, with hydrogen to form water. Even the diatomic molecule (O_2) that occurs in the air we breathe is reactive enough to form ferric and carbonate compounds. Those compounds should be abundant on a planet, but pure oxygen, whether monatomic or molecular, should be vanishingly scarce—as it is, in fact, on Mars and Venus.

When Earth's atmosphere formed 4 billion years ago, pure oxygen was probably rare here, too. Hyperactive volcanoes, more common during Earth's early years than they are now, cloaked the primordial planet with nitrogen, sulfur dioxide, carbon dioxide, and water vapor. But sometime around 2 billion years ago the oxygen presence began to increase, soon reaching levels of between 5 and 18 percent of what we have today. The evolution of life, of course, was what made that possible. Photosynthetic organisms, using chlorophyll and other pigments to capture sunlight, were turning carbon dioxide and water into molecular oxygen. As those new forms of life flourished, oxygen began to be pumped ever faster into the atmosphere. Earth blossomed with life, the composition of its atmosphere closely coupled to the evolutionary process that was taking place in its seas and on its continents. With every breath we take, we benefit from that momentous chain of events.

Nick Lane, an English biochemist, has written a meticulously detailed history of oxygen on our planet, organized around two major themes. The first is the tricky problem of how the presence of atmospheric oxygen has risen to its present level over time. Alternating layers of red- and black-banded ironstone, as well as coal beds, provide some benchmarks, because the rusting of iron and the fossilization of coal depend on how much oxygen is present in the air. Pockets of "ancient atmosphere," trapped in 100-million-year-old amber, may add direct evidence: in the mid-1980s geochemists using a quadrupole mass spectrometer measured the oxygen in amber samples from various geologic periods and reported that atmospheric O_2 levels had been higher than 30 percent during the Cretaceous Period, nearly twice what they are today. (According to Lane, however, the controversy is still raging within the scientific community about whether the air inside amber has been hermetically sealed since the time it solidified from drops of tree sap.) And the size of fossilized insects provides tantalizing, albeit indirect, clues that

the atmospheric oxygen level may have been much higher during the age of the dinosaurs.

Only with such high levels of oxygen, Lane argues, could a Carboniferous dragonfly called *Meganeura*, which had a wingspan of almost a yard, have been able to fly. (The largest modern dragonflies, by comparison, are no more than four inches across.) In the end, such high oxygen levels may have been lowered by a worldwide firestorm that ended the age of the dinosaurs 65 million years ago. According to this scenario, the highly oxygenated atmosphere was sparked by an incoming asteroid, and the forests lit up as if they were tissue paper.

Lane then jumps to a second major theme: the role of oxygen in health and longevity. Fragments of molecules containing oxygen, called free radicals, form during the natural process of respiration. Free radicals can chemically alter the normal functioning of cells. According to a growing body of evidence, the accumulated damage plays an important role in aging. Oxygen, in effect, is a highly reactive fuel; the cell, in relying on oxygen to promote life, courts death and, sooner or later, succumbs. Lane's book ranges widely over a host of topics, from the usefulness of antioxidants such as vitamin C in curing colds, to the potential for prolonging human life with enzymes that repair damaged DNA. And it turns out that the jump from the geologic theme in the first part of the book to the medical theme in the second is not as great as it seems. A unifying thread of Lane's narrative, fascinating in its irony, binds it all together: oxygen, essential element of life, is also an agent of death.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

nature.net

Big-Fish Drought

By Robert Anderson

On a recent deep-sea fishing trip—my first—off the coast of southern California, the yellowfin tuna were nowhere in sight. We were surrounded instead by scores of other boats, all equally idle, and the only fish I saw all day were the silvery small fry used for bait, swimming in tight circles in their holding tank.

That same week, as it happened, the journal *Nature* published a startling report on the rapid decline of large ocean species all over the globe: populations of fishes such as cod, halibut, marlin, shark, swordfish, and tuna have sunk to about 10 percent of their pre-industrial levels. Not only are big fish disappearing at an alarming rate, but the top predators are also only about a fifth to a half the size they once were. You can access recent news stories about these and other, related findings at www.seaweb.org. To view graphs and charts that summarize the depletions, go to ram.biology.dal.ca/depletion and scroll down the page.

The importance of large marine fishes, of course, goes far beyond sport; they are vital to the health of marine ecosystems. At "Oceana" (www.oceana.org) click on "Empty Oceans—Where Are the Fish?" to learn how large-fish species and other marine animals become casualties, or "bycatch," of such industrial fishing gear as pelagic (oceanic) longlines, gill nets, and shrimp trawls.

Rational management of large-fish populations, moreover, would have enormous economic benefits worldwide. To bone up on current policies and proposals for restoring and safeguarding fish populations, go to "Environmental Defense" (www.edf.org) and click on "Oceans." You can also select "Marine Protected Areas" and "Sustainable Fishing" from the drop-down menu at the right. Or consult "American Oceans Campaign" for a long list of multiuse fish links (americanoceans.org/fish/link.htm). Finally, to view the results of an unusual effort by private citizens to protect the Gulf of California (also known as the Sea of Cortez), take a look at www.seawatch.org. Be sure to scroll to the bottom of the page to read the bad news firsthand from a series of interviews with Mexican fishermen.

The rapid decline of "big game" fish in the last few decades has not gone unnoticed among sport fishers. To get some idea of how it used to be, go to www.antiquefishingreels.com and click on "Classic Fishing" in the tool bar at the left: you'll find vintage photos of Ernest Hemingway and Zane Grey, among others, with their prize trophies. Then go to a site maintained by consultants for private-sector clients trying to protect marine fisheries and habitats (Chambers-Associates.org/Big-Marine-Fish/home.html). Click on "Daily 'Kill-o-Meter'" to learn how the ongoing decimation of big fish is tied to the phases of the moon. (Commercial longliners fish hardest on bright nights when swordfish—their primary targets—feed most actively and closest to the surface; many other large species are killed incidentally.)

As consumers, we are all affecting the ocean's ecosystem every time we choose a fish to buy. At the Monterey Bay Aquarium's Seafood Watch Web page (mbayaq.org/cr/seafoodwatch.asp), type in your favorite fish to find out if its catch is putting additional pressure on one of the world's critically low fisheries.

Robert Anderson is a freelance science writer living in Los Angeles.

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Hazy, Hot, and Hidden

Dust-laden clouds at the centers of some galaxies may enshroud titanic starbursts or baby quasars.

By Charles Liu

Galaxies illuminate the universe, and not just with visible light. Think, for a moment, about an incandescent light bulb—it's not only bright, it's hot, too; and the heat we feel comes mostly from infrared radiation emitted by the bulb's filament. Similarly, stars in galaxies pour out visible light, as well as plenty of radiation at wavelengths beyond the visible, such as infrared and ultraviolet. A typical galaxy (or more precisely, its constituent stars) emits that invisible radiation much the way the light bulb does: roughly proportional to the amount of visible light it emits. Our Milky Way, with its several hundred billion stars, is a fine example of a galaxy that emits light broadly over the range of the electromagnetic spectrum.

Russell Mills, *Between Two Lights*, 1994–95

There are, of course, some spectacular exceptions. In the 1980s surveys by NASA's Infrared Astronomical Satellite revealed an entire class of galaxies shining far more intensely in infrared light than they did in visible light. We astronomers, straightforward as always, named the group "luminous infrared galaxies"—LIRGs for short—and the brightest among them, "ultra-luminous infrared galaxies" (ULIRGs). Some of the LIRGs emit more than 90 percent of their energy as infrared radiation; the brightest ULIRGs generate a hundred times more infrared energy than the total energy output of the Milky Way—at all wavelengths combined.

Those findings were more than puzzling. No normal population of stars can produce so much infrared energy without generating a corresponding amount of visible light. Something else in those galaxies must be converting most of the visible light into infrared light. For that matter, the total energy output, whatever the wavelength, was (and remains) a mystery. Whatever generates the observed energies streaming out of a LIRG must be far more powerful than any collection of stars known.

In the past twenty years astronomers have learned that the "infrared converter" is a cloud of intervening dust. Now, in a recently published study, Aaron S. Evans, an astronomer at Stony Brook University in New York State, and his collaborators have focused on the riddle of the total output energy. They haven't identified the energy source churning inside LIRGs—mainly because of an obscuring cloud of dusty gas—but they have offered new insight on how LIRGs might be put together.

According to recent measurements, about half of the background light generated in the universe today (not including the cosmic background radiation left over from the big bang) originates from LIRGs. LIRGs typically radiate more energy in just a few seconds than our Sun does in millennia. It is also known that the energy from LIRGs originates from compact regions near their galactic centers.

So what is the likely source of such energy? Think about how stars arise [*see "Universe: Dust to Dust," by Neil deGrasse Tyson, May 2003*]. Deep within interstellar clouds of gas and dust, dense clumps form and collapse under their own weight. Eventually the collapsed matter becomes so dense and hot that nuclear fusion begins, and the clumps become fledgling stars. Millions of years later, the

stars' radiation ionizes the clouds still surrounding them and pushes the clouds away, unveiling the bright new stars to the rest of the universe. But while the stars are being formed, all that's visible from the outside is the dust and gas surrounding them.

The clouds that enshroud the center of a LIRG are thousands of times more massive than typical star-bearing clouds, but they may be analogous. Current models suggest that the object they hide—the energy source for the LIRG's radiation—could take one of two forms. It might be an aggregate of billions of stars formed in a massive burst in the recent past. Or it might be a single supermassive black hole—a newborn quasar, still swaddled in a cocoon of dusty gas—much larger than the black hole now thought to lie at the center of the Milky Way [*see "Peering at the Edge of Time," by Fulvio Melia, June 2003*]. In that case, the energy output would come from huge amounts of potential energy released by matter falling into the black hole.

In either case, the dust surrounding the energy source would absorb visible and ultraviolet light and re-emit it later as infrared light. That's why almost all the radiation coming from LIRGs is infrared. All that remains, then, is to confirm either one of the two scenarios; if one is confirmed, astronomers will know which objects, stars or black holes, emit half of the background light in the universe.

But as much as we would like to glimpse the center of a LIRG, the dusty, surrounding clouds present a daunting observational obstacle. Dust not only quenches visible light, but it also degrades our view. Imagine watching from a distance as a powerful searchlight shines into a pea-soup fog. From a distance you can see a bright glow coming from a spot in the fog, but you can't make out its source. That's exactly what we have to deal with when we look at a LIRG. Dust in the universe, like earthly fog, scatters light; it turns straight beams of light into a crisscrossing mishmash of unfocused glare. And because the cloud itself is aglow in infrared light—also an effect of dust—seeing inside it is all the harder.

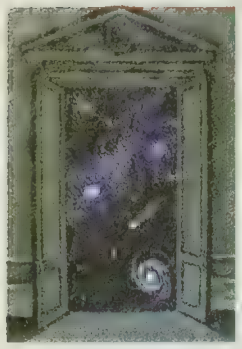
Ironically, it turns out that to peer through the haze, we need to look for emissions from the interior energy source at infrared wavelengths. Radiation at the relatively long wavelengths of infrared light slips past the dust more readily than visible light does. A bright spot against the overall infrared glow would mark the position of the galaxy's power source. Then, to distinguish between a single supermassive black hole and a clutch of hot, young stars, astronomers need high-resolution images of that hot spot.

Evans and his collaborators studied NGC 4418, a relatively "nearby" LIRG about 90 million light-years from Earth. They aimed two infrared camera systems—NICMOS on the Hubble Space Telescope and MIRLIN on the Keck Telescope in Hawaii—in an effort to pierce the haze surrounding the galaxy's central engine. Their observations confirmed that the galaxy's vast infrared luminosity originates from a high-powered, compact energy source. But even with these powerful infrared instruments, they couldn't see all the way to the center of the LIRG. An inner dust cloud, several hundred light-years across, obstructed their attempts to identify the source—star cluster or black hole—of the galaxy's prodigious radiation.

To put things into perspective, the density of all that obscuring dust is, on average, a few grains per cubic centimeter—far, far cleaner than the air we breathe. Yet it's still enough to confound our best astronomical technology, and to keep us wondering about the mysterious source of power that lurks in LIRGs.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

By Joe Rao



Mercury makes an evening appearance, albeit a poor one, during late July and early August. The little planet shines above the west-northwestern horizon about forty-five minutes after sunset, then follows the Sun behind the horizon fifteen minutes later. Otherwise it's not visible. Two conjunctions are of note: On the evening of July 25 Jupiter slips less than one-half a degree to the south of Mercury, but the king of the gods is four times brighter than the gods' messenger. On the evening of the 30th Mercury passes a fraction of a degree north of the blue star Regulus; in this instance, the gods' messenger is four times brighter than the little king (which is what "regulus" means). Binoculars, a "severe-clear" sky, and an open view to the horizon are practically musts to catch these events. Mercury vanishes into the blaze of sunset around the middle of August.

Venus lingers in the dawn sky and is still detectable in early July roughly thirty minutes before sunrise; look for it just two degrees above the east-northeastern horizon. The planet's proximity to dawn's rosy fingers makes it hard to see. Binoculars certainly help; with such aid Venus may actually appear quite brilliant despite the bright morning twilight. Venus passes behind the Sun on August 18, leaving the night sky until late September.

Mars gets top billing throughout July and August. Rising in the east-southeastern sky, the yellowish-orange "star" looms ever brighter as it approaches its rendezvous with Earth in late August. It rises about three hours after sunset on July 1, but less than two hours after sunset by the 31st. As its distance from the Earth closes from 52 million to within 39 million miles, the planet brightens from magnitude −1.4 to −2.3. The waning gibbous Moon passes exceedingly close and to the south of Mars during the predawn hours of July 17—in fact, Floridians living south of a line running roughly from Fort Myers to Vero Beach will see the Moon occult, or hide, the planet at around 4:14 A.M. Mars's disk, readily visible through a telescope, expands throughout July, making surface features easier to see.

During August Mars rises about four minutes earlier each night and becomes simply dazzling, shining at magnitude −2.9 from August 22 until September 3. During this apparition Mars is the closest it has been to Earth in nearly 60,000 years.

In late August Mars will be closer to Earth than it has been in nearly 60,000 years.

Anyone who has a telescope will want to find out what it can do when it's trained on Mars this August. What's to be seen there? By now (it's mid-spring on southern Mars) the south polar cap should have shrunk to a small white speck. White clouds may highlight the disk elsewhere. The largest dark markings should be fairly easy to see with almost any telescope at 100-power and greater, but the finer details are always hard to resolve. Mars comes closest to the Earth on the morning of August 27 at 5:51 A.M. The distance between the two planets, measured from center to center, will be just 34,646,418 miles. The next day Mars reaches opposition to the Sun.

Jupiter begins July as the brightest "star" in the evening sky, but by mid-month you may need binoculars to spot it as it sinks deep into the glow of sunset. On the evening of July 2 a three-day-old crescent Moon passes four degrees north of Jupiter. Later in July Jupiter pairs off with Mercury, as I noted earlier. In August Jupiter is unobservable; it reaches conjunction with the Sun on the 22nd.

Saturn, too, is lost in the solar glare as July begins. It emerges into view by the 15th; look above the east-northeastern horizon about an hour before sunrise. By month's end it's coming up about two-and-a-half hours before the Sun. By August Saturn has moved into the constellation Gemini, and its visibility in the morning sky improves; the planet is well above the eastern horizon as dawn breaks. On the morning of the 23rd Saturn can be found near the crescent Moon, shining at magnitude 0.2.

The Moon in July reaches first quarter on the 6th at 10:32 P.M. It waxes full on the 13th at 3:21 P.M., and wanes to last quarter on the 21st at 3:01 A.M. The Moon is new on the 29th at 2:53 A.M. In August the Moon reaches first quarter on the 5th at 3:28 A.M. and becomes full on the 12th at 12:48 A.M. It wanes to last quarter on the 19th at 8:48 P.M. and returns to new on the 27th at 1:26 P.M.

The Perseid meteor shower, on the night of August 12–13, is spoiled this year by the light of a full Moon. Perseids are typically fast and bright, and they frequently leave long-enduring trails; the best hope for seeing them is to look in a direction of the sky away from the Moon.

Earth reaches aphelion—its farthest point from the Sun—on July 4 at 2:00 A.M. Our star is 94,510,793 miles away.

Unless otherwise noted all times are given in Eastern Daylight Time.

EXPLORER GUIDE

YOUNG NATURALIST AWARDS 2003

Scientific discovery begins with expeditions.

Over the past 134 years, American Museum of Natural History scientists have mounted thousands of expeditions to observe, gather, and analyze data to further our understanding of the natural world and human culture. Now in its sixth year, the Museum's National Center for Science Literacy, Education and Technology's Young Naturalist Awards program challenges students in grades 7 through 12 to embark on their own scientific expeditions, exploring and reporting on a question in biology, Earth science, or astronomy.

These expeditions need not involve specialized equipment or travel to distant lands. Science can begin with a keen eye and a backyard. From a park in Brooklyn to the rain forest of Hawaii, from a home aquarium to the coastal waters of Nova Scotia, this year's Young Naturalists met their challenge with a passion for inquiry, a recognition of the interdependence of life, and a concern for the human impact on the environment.

The winning entries (chosen from nearly 800) are summarized here. To read the complete essays on the Museum's Web site, which also features a brief profile of and interview with each winner, visit www.amnh.org/youngnaturalistawards.

Entries are already being accepted for the 2004 Young Naturalist Awards and will continue to be accepted until January 9, 2004.

The Young Naturalist Awards are made possible by a generous grant from The J.P. Morgan Chase Foundation.

Oscawana: A Dying Lake?, by Sarah Beganskas (Woodland Middle School, East Meadow, New York; Grade 7)

While on vacation in upstate New York, Sarah decided to find out why the once crystal clear waters of Lake Oscawana were turning a murky green. Not only did she discover the causes of the lake's problems, she also discovered what local residents are doing to save the lake.

"I hope that the lake will improve so that my children and grandchildren can enjoy its beauty and recreational uses, as my great-grandfather envisioned. By doing this project, I have discovered more about the lake I have known and enjoyed my entire life."

Bobwhite Quail Decline in Texas, by Donald Capra (Branch and Leaf Academy Home School, Abilene, Texas; Grade 11)

Concerned that bobwhite quail might be on their way toward extinction, Donald volunteered for the Texas Quail Index. As a member of the TQI, Donald examined the factors that affect quail populations on his family's ranch. He conducted surveys which he hopes to use to develop a management plan that will help to reverse the trend in quail decline.

Bobwhites roost in a circle for protection.

"Now that I have completed my first year of observations...I feel that I know our land better and the animals that live there, too....I am glad I can enjoy the early-morning call counts."

Aspen Island, by Elspeth Iralu (Home School, Gallup, New Mexico; Grade 10)

While hiking with her family, Elspeth came upon an aspen grove in a valley where aspens are scarce. Her investigation centered on the environmental

ELSPETH IRALU

Aspen grove near Lost Lake, New Mexico

characteristics that favored aspen growth in this location. She compared the aspen grove with a control area, examining factors such as elevation, humidity, and temperature.

"From where I stand, I can't see the emerging patterns in my life. I only remember moments and short seasons. But aspens look back 10,000

years and see what has changed. I am dwarfed by tall trees with long memories."

Exploring the Mystique of the Mushroom, by Yushan Kim (Athens High School, Troy, Michigan; Grade 12)

Yushan ventured into her backyard—rich in biological activity due to a large amount of decaying wood. Having never seen a mushroom there before, she was surprised when she found one cluster and then another. In her investigation, Yushan examined the connection between these organisms and their environment, generating informative illustrated charts, field sketches, and photographs.

"Natural wonders awaiting our discovery teem all around us, even in the tiniest of environments. Discovering them for myself has been a wonderfully fulfilling experience."

Worms in Prospect Park, Brooklyn, by Linda Lam (Gladstone H. Atwall Middle School 61, Brooklyn, New York; Grade 8)

While looking for worms for a fishing trip, Linda became intrigued: why were worms found in some locations and not in others? She investigated three locations in her local park to determine what environmental factors contribute to varying worm populations.

LINDA LAM

Spiders prey on earthworms, contributing to low population densities.

"Completing these field expeditions has given me greater insight into how scientists observe and study the world around them. During my expeditions, I got a glimpse of an underground world located just across the street from where I live."

Survival in the Northeast Wilderness, by Seth Levin (Moses Brown School, Providence, Rhode Island; Grade 9)

After watching some news stories of hikers being lost in the woods, Seth theorized that a lost individual could survive on what he or she found in the forest. After several expeditions to a local nature reserve, Seth compiled a long list of edibles and concluded that the forest was a virtual smorgasbord of nutritious and tasty berries, nuts, leaves, and fungi.

SETH LEVIN

The parasol mushroom *(Leucocoprinus procera)*

"Until now, I hadn't realized the importance of these local plants, trees, and mushrooms, many of which I had seen while walking in the woods around my home."

Comparing Streams in Southwest Washington to Determine the Needs of Salmon, by Kristen Marini (Maple Grove Middle School, Battle Ground, Washington; Grade 8)

Kristen focused on a question: why hasn't there been a large salmon run in Salmon Creek since the early 1990s? She compared local streams in southwest Washington, some of which have healthy salmon runs, to determine what environmental factors are beneficial to salmon. She discovered that some parts of Salmon Creek are polluted and the probable cause for the lack of salmon runs.

"I would like to travel to other creeks...and examine them to see if they are providing the basic requirements for salmon, and to ensure that my findings are not coincidental."

KRISTEN MARINI

A butterfly seen along the stream in Pumice Plains, Washington

Arsenic and Zinc Distributions in Streams near Park City, Utah, by Doug Naftz (Park City High School, Park City, Utah; Grade 10)

After learning that his city's drinking water supply contained elevated levels of zinc and arsenic—both toxic to humans—Doug built a miniature permeable reactive barrier chamber to see if he could remove arsenic from water he collected. His experiment was a success. He concluded that if PRBs are installed in the main tunnel that supplies water, then enough arsenic could be removed to lower the concentration to acceptable levels.

"After identifying that there was a serious problem concerning arsenic in the streams and possibly in the drinking water of Park City, I decided to see if there was a natural and cost-effective way to remove it."

Surviving against All Odds: Investigating the Adaptability of the Common Periwinkle, by Natalie Parks (Halifax West High School, Halifax, Nova Scotia; Grade 12)

Natalie decided to investigate the biological implications of a polluted environment using periwinkles. She collected periwinkles from the North West Arm area of Halifax and also from a pristine environment and compared them. She concluded that chemical changes alone in its environment will not eradicate the periwin-

kle as it will always find ways to adapt.

"Examining this species has given me insight into the ability of creatures to adapt to even the most hostile of environments...I have a greater appreciation for the survival abilities of all creatures."

KYLE SHEETS

This 25-foot-tall saguaro is estimated to be 100 years old.

Aquarium: An Ecosystem in Miniature, by Charlotte Seid (Thomas Jefferson High School for Science and Technology, Alexandria, Virginia; Grade 9)

A tropical fish enthusiast, Charlotte decided to examine the aquatic community she had created in an aquarium in her home. During her expedition she examined how each fish species adapted to the aquarium environment, and observed how fish that never meet in nature interacted.

"Through observing, sketching, and ultimately becoming more familiar with my aquarium and its piscean inhabitants, I realized how natural forces and behaviors are prevalent even in an artificial setting."

Saguaro Cactus: From Life to Death, by Kyle Sheets (Doolen Middle School, Tucson, Arizona; Grade 7)

Kyle wanted to see if he could find examples of each stage of a saguaro's life. He made several trips to the Sonoran desert where he documented, in words and images, the life cycle of this monumental plant.

"After spending all this time with the saguaro cactus, I felt as if I had gained another friend....I learned that being a scientist is a lot of work, but also a lot of fun."

A Comparison of Native Tree Seedling Growth on Fallen Hapu'u Ferns and the Adjacent Forest Floor in Volcano, Hawaii, by Kolea Zimmerman (Waiakea High School, Hilo, Hawaii; Grade 11)

Venturing into the rain forest just behind his house, Kolea noticed an abundance of tree seedlings growing on the fallen logs of the hapu'u tree fern. He hypothesized that the fallen hapu'u logs served as "nursery logs" for the development and growth of certain species. To test his hypothesis, he compared the number of seedlings and saplings on hapu'u logs to the number of seedlings and saplings on an equal area next to the logs.

KOLEA ZIMMERMAN

The endangered oha' grows in the Hawaiian rain forest.

"Fond childhood memories always included being respectful of all the native plants. We were taught from a very young age to respect the hapu'u and other native plants of our forest."

MUSEUM EVENTS

EXHIBITIONS

Chocolate

June 14–September 7
Gallery 3, third floor

The delicious story of chocolate spans more than two thousand years. This fascinating exhibition will explore the legends, history, ecology, economics, and enduring allure of this delectable phenomenon.

Chocolate *and its national tour were developed by The Field Museum, Chicago. This project was supported, in part, by the National Science Foundation.*

Chocolate Tastings and More

Weekends during the run of *Chocolate,* you can sample fine chocolate in the retail shop outside the exhibition or in the Food Court and purchase luxurious treats. Visit www.amnh.org for a schedule of events.

Vietnam: Journeys of Body, Mind & Spirit

Through January 4, 2004
Gallery 77, first floor

This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the **Freeman Foundation.** *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

Discovering Vietnam's Biodiversity
Through January 4, 2004
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

DEMONSTRATION

Traditional Mexican Chocolate Preparation
Saturday, 7/26, 3:30–4:30 p.m.
With Zarela Martínez, restaurateur and cookbook author.


©2002 THE FIELD MUSEUM, TERESA MURRAY

Molinillos are used to blend and froth chocolate.

LECTURES

Art(ifacts) and Science of Chocolate
Thursday, 7/17, 7:00–9:00 p.m.
Museum-inspired chocolate sculptures will be showcased and discussed.

Pre-Columbian History of Chocolate
Saturday, 7/26, 2:15–3:15 p.m.
With Michael D. Coe, author of *The True History of Chocolate.*

Experience the sights and sounds of a bustling

Vietnamese Marketplace

and sample traditional foods at Café Pho.
Through January 4, 2004

77TH STREET LOBBY, FIRST FLOOR

The Indigenous Peoples of Guyana
Saturday, 8/9, 1:00–2:00 p.m.
Lal Balkaran discusses indigenous Guyanese cultures.

Africa: Facing the Challenges of Globalization
Sunday, 8/10, 2:30–4:00 p.m.
This panel examines how multinational partnerships affect the local economies and peoples of Africa.

PERFORMANCES

Passing on Traditions: Aztec Music and Dance
Saturday, 8/9, 2:15–3:15 p.m.
The ancient music and dance of Mexico.

Kotchegna Dance Company
Sunday, 8/10, 1:15–2:15 or 4:15–5:15 p.m.
Stories from the Ivory Coast.


COURTESY CTMD

Kotchegna Dance Company

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe
The Structure of Our Galaxy
Tuesday, 7/1, 6:30–7:30 p.m.
Our Place in the Universe
Tuesday, 8/5, 6:30–7:30 p.m.

Celestial Highlights
Stars of Summer
Tuesday, 7/29, 6:30–7:30 p.m.
Here's Mars!
Tuesday, 8/26, 6:30–7:30 p.m.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

Starry Nights: Live Jazz

Friday, 7/4, 5:30 and 7:00 p.m.
Norman Hedman's Tropique

Friday, 8/1, 5:30 and 7:00 p.m.
Visit www.amnh.org for lineup.

The 5:30 performance on 8/1 will be broadcast live on WBGO Jazz 88.

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On Hostile Ground

By Oliver L. Gilbert

Only once have I been seriously embarrassed while searching for lichens. The incident took place in 1999, a more innocent time, before it became pretty much unthinkable to "wander onto" a military installation. I was poking around the perimeter of a military airfield in Cornwall, England, the inside of which, even then, was strictly "off limits." But there was no one around, and the control tower was just a smudge on the horizon. I crawled through a hole in the fence and started my survey.

Why would I take such a risk? Lichens have been intensively studied in Great Britain by an army of amateur naturalists since about 1750. In the beginning they came from the leisured class of doctors, clergymen, and the landed gentry. But soon they were joined by members of all classes: schoolteachers, gardeners, coal miners, peddlers, even a Scottish umbrella maker. In short, thousands of lichenophiles have been crisscrossing the countryside for more than 250 years.

That long history of study has created a dilemma for modern British lichenologists: how can one make one's mark in such a well-tilled field? An ability to think laterally helps. But true devotees recognize that the key to discovery lies in new habitats that are emerging all the time in unlikely places, many virtually unexplored.

The first neglected habitat I discovered was associated with the pylon towers that support high-voltage lines. The pylons are coated with zinc, and so the ground underneath them gets a highly toxic drip during rain. That keeps out most of the higher-order plants, but it opens up a niche to swards of tiny lichens belonging to little known species.

Not only are such "pylon lichens" rare, but their biology is unusual in other respects as well. Instead of being slow growing, like most lichens, they can complete their life cycle in less than a year. Their natural habitat is the spoil heaps of heavy-metal mines. I spent one holiday following pylon lines across the countryside before turning to a similar niche—the ground under the galvanized crash barriers beside the British motorways. Word soon spread, and it wasn't long before my North American colleagues were recording similar species along the interstates and around other American analogues to the British sites.

Lichens can grow in such stressed places because they are made up of fungi and algae living together symbiotically: the algae supply the fungi with carbohydrates, and the fungi supply the algae with minerals and much-needed shade. When they team up that way, they can live closer to the poles, higher up in the mountains, and farther out in the deserts than other organisms can.

Lichen community (mixed species), Golspie, Sutherland, Scotland

What is more, they can live in places that didn't even exist in the earliest days of lichen-hunting—industrial wasteland, concrete structures, tarmacs, railway lines, abandoned cars. All have proved fruitful.

The day I crawled through the fence around the airfield, it was high summer, and the air was still enough for me to hear the sound of bees droning. I was also aware of—though, as usual, indifferent to—the human activity around me, the occasional helicopter flying overhead. But a pilot must have spotted a furtive figure walking, stooping, sometimes lying prone. Before long a Land Rover full of armed guards in riot gear pulled up beside me, no doubt wary of the hammer and chisel I was clutching. I pleaded that I was just a harmless "nature watcher," pursuing my hobby. But the station commander was not amused. He gave me a dressing down, and sent me packing.

Oliver L. Gilbert is a retired lecturer from Sheffield University, England. He has been interested in botany since an early age.

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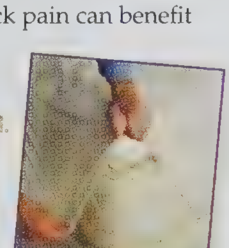
The Memory Foam Ultra mattress topper is cut into a grid pattern combining six different zones for variable support, and a better night's sleep.

The 2-inch thick temperature-smart foam adjusts to your shape.

It's 3 a.m. You have exactly two hours until you have to get up for work, and you still can't seem to fall asleep. At this point, the phrase "tossing and turning" begins to take on a whole new meaning for people whose mattresses simply aren't giving proper support anymore. Your mattress may dictate your quality of sleep. Even if you merely suspect that your mattress may be outdated, that's when you need to take action. Some mattresses fail to support your spine properly, which can result in increased pressure on certain parts of your body. Other mattresses, sporting certain degrees of visco-elastic foam, can sometimes cost you well over $1000. Now, one of the world's leading manufacturers of foam products has developed an incredibly affordable mattress topper that can actually change the way you sleep. Introducing the future of a better night's sleep: The Memory Foam Ultra Mattress Topper.

Wake up to a better morning. The Memory Foam Ultra mattress topper is designed to give you a better sleep surface. Not only does it support each region of your body, but it's also temperature sensitive. With its various-sized "comfort cells," the 2-inch thick Memory Foam Ultra mattress topper combines six zones to support specific body area weight, which promotes a better night's sleep. The largest cells support your lower back and midsection, while the medium-sized cells support the shoulders, lower back and legs. The smallest cells support your head and feet. Combined, these zones provide variable support from head to toe. By using visco-elastic foam, the Memory Foam Ultra mattress topper also molds to your body contours to help prevent tossing and turning during the night. When you lie down on this amazing material, the heat and pressure sensitive foam reacts to your body's weight and temperature, so that it molds to your exact body shape. This means that whether you sleep on your back, stomach or side, your weight is evenly distributed and your spine remains in a neutral position. Other surfaces support your body at the shoulders, hips and legs only. This causes your spine to sag in other areas, which can often result in discomfort, and even back pain. You'll wake up rested, relaxed and ready to take on the day. Anyone who suffers from insomnia and back pain can benefit from this technology.



FREE heavyweight mattress pad included. Included with the Memory Foam Ultra mattress topper is a fitted mattress pad. It's heavyweight and quilted, and made of 200-count 100% cotton with a 15-inch deep fitted spandex skirt to fit a mattress up to 21 inches thick. The size of the mattress pad is determined by the size mattress topper you order.

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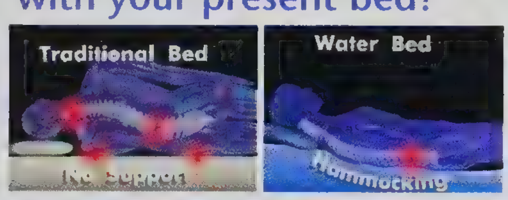
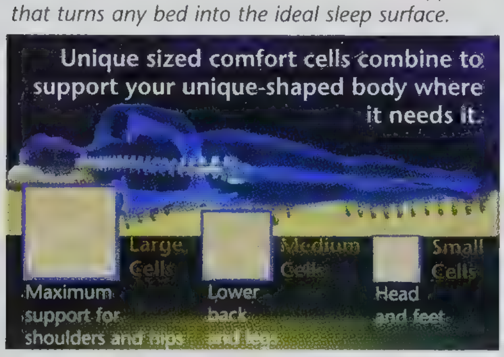
What could be wrong with your present bed?



The ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind Memory Foam Ultra, the mattress topper that turns any bed into the ideal sleep surface.



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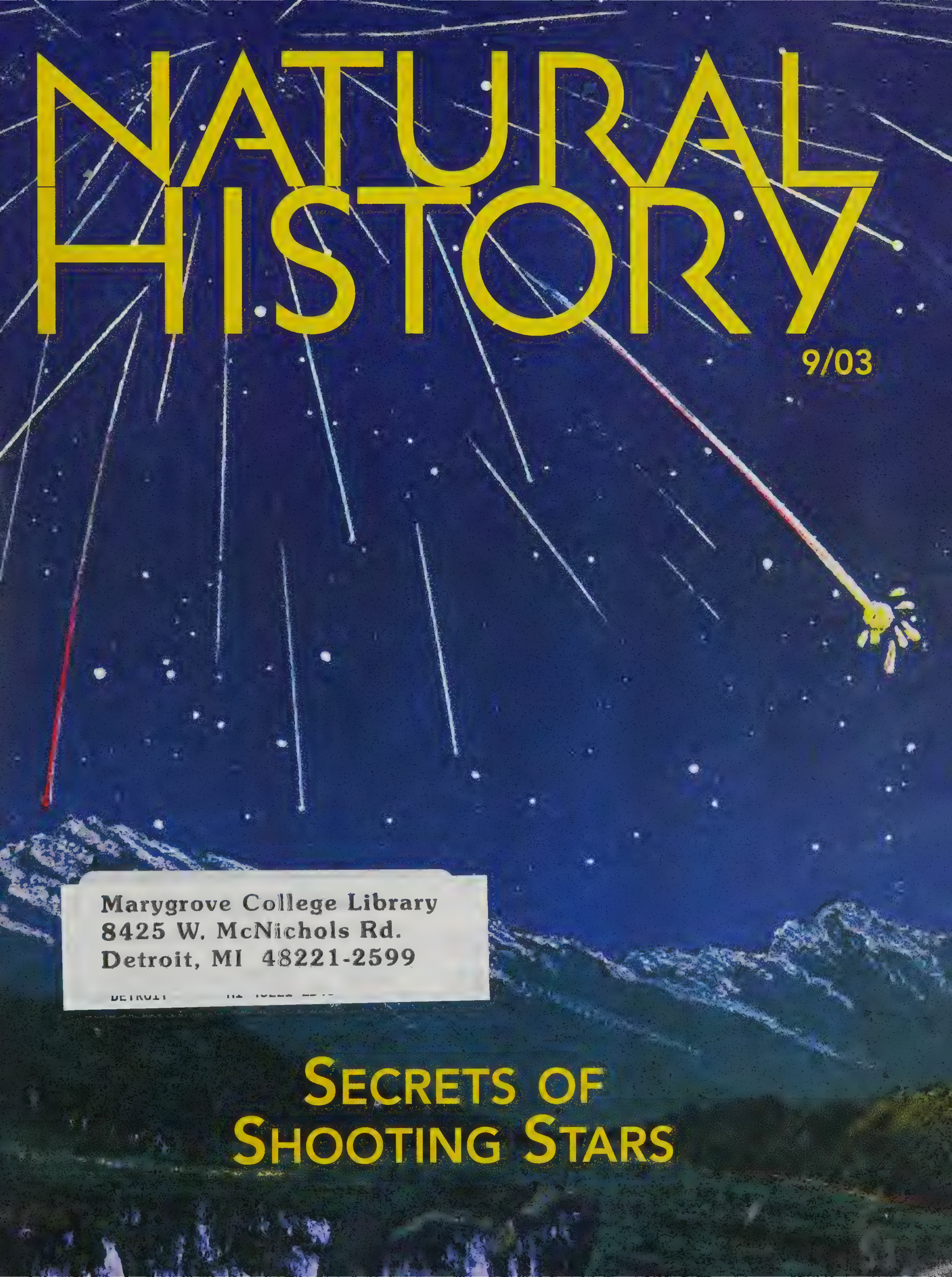
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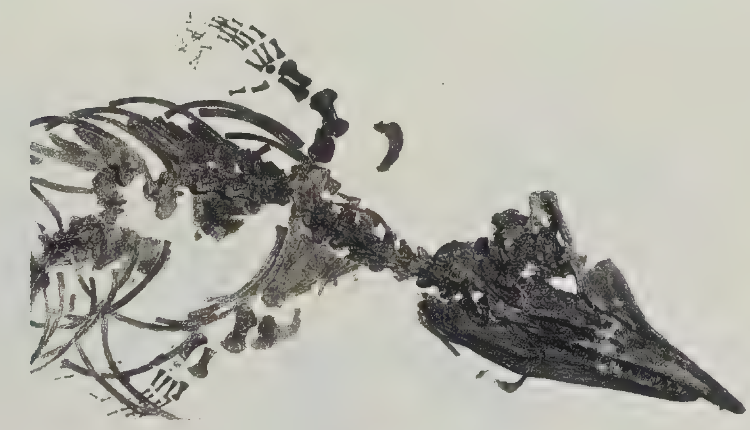

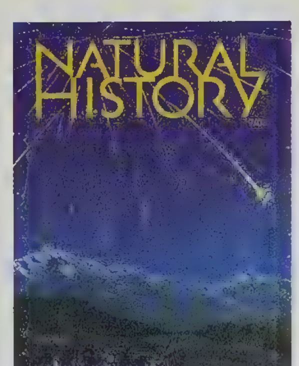

COVER
Nineteenth-century lithograph of a meteor shower

STORY BEGINS ON PAGE 28

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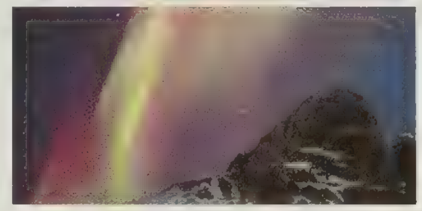
DEPARTMENTS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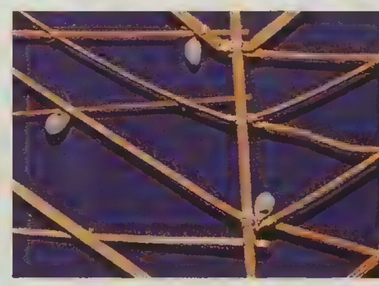
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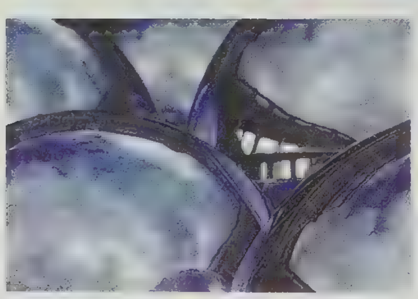
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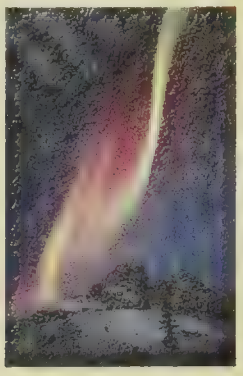
Cold Fire of the Night

Photograph by Art Wolfe

See preceding pages



Aurora was the radiant Roman goddess of dawn, a charioteer who could light up the night sky. Her namesakes, the aurora borealis and aurora australis, are similarly un-Earthly: electrons and protons pour out of the Sun and speed through space until they hit a region rich in gases—the atmospheres of most planets and of a few moons do nicely. As the particles collide with different gases, they trigger colored light-works: red or green from oxygen, for instance, or blue or violet from nitrogen.

If Earth had no magnetism, like Venus, the light show would be erratic. If Earth were magnetized closer to its equator, as Neptune is, Mexico City would be prime for viewing. As it is, auroras on Earth follow magnetic lines of force that converge at the north and south magnetic poles. They can be seen year-round; check the Internet for readily available aurora "weather" forecasts.

Eager to capture the lights, photographer Art Wolfe took the frozen Dalton Highway, which stretches 414 miles from Fairbanks to Prudhoe Bay, Alaska. He watched the aurora reel and dance in pale greens for two hours above the Brooks Range. What he found most mystical was that "when the film was developed, there were lovely reds that had been there, but just couldn't be picked up by the naked eye."

—*Erin M. Espelie*

Hard Rain

Every year about this time, when the night skies are clear, and when standing still under the stars for half an hour doesn't call for a parka, I like to go outside and take in the show. It's pretty simple astronomy: orient to a few constellations, vaguely familiar from the same splendid viewing last year; check out Joe Rao's latest almanac of the Moon and planets (see "The Sky in September," page 65); and, with any luck, "catch a falling star."

Most meteors are nothing fancy: a fleeting streak, often not very bright. A friend to say, "Hey, look!" is nice, because if you glance in the wrong direction, it's gone. But if rocks from the sky seem a small thing, no more consequential than the fireflies of July and August, take a look at the Moon. Turn to page 46 for the gallery of lunar photographs that accompany G. Jeffrey Taylor's article, "Moonstruck." Make a mental note of the chaotic surface. And the next time you're looking at the real Moon, imagine that you're a time traveler, gazing at the Earth as it appeared, say, four billion years ago.

It's easy to forget that the Moon records the history of our own cosmic neighborhood. The Earth, too, was once subjected to an inconceivably violent rain of rock—and without water or an atmosphere, our planet, too, might still look like the wasted battlefield of an epic war. The story of meteorites, as Donald Goldsmith tells it in his "Bolts from Beyond" (page 28), is a tumultuous one, but it is also a story with great scientific promise: a few dozen meteorites have been identified from the Moon, Mars, and the asteroid Vesta, serendipitous gifts from the cosmos that carry vital clues about our planetary origins.

To most people, though, the most noteworthy meteorite of the Earth's past was the one that killed the dinosaurs. That, too, was probably a lucky accident—for us. It's hard to imagine how we mammals could have so thoroughly covered the Earth had the killer asteroid not knocked off some big reptiles and opened up some turf. In his article "Terrible Lizards of the Sea" (page 36), Richard Ellis describes one of the more successful families of prehistoric creatures with large teeth that ever roamed—or at least swam—the Earth: the mosasaurs. Mosasaurs had flourished for a long time, 25 million years, and there is no reason to think they were on their way out when they were abruptly extinguished. We may owe our very existence to a big, fast-moving rock.

This month the newly renovated Arthur Ross Hall of Meteorites reopens at the American Museum of Natural History. Anyone fortunate enough to visit will find plenty more reasons there, as our columnist Neil deGrasse Tyson ("Universe," page 18) puts it, to "keep looking up."

—PETER BROWN

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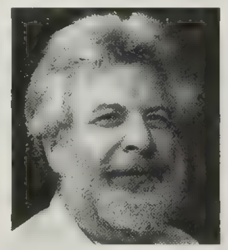
CONTRIBUTORS

In his twenty-five-year career Seattle-based photographer **ART WOLFE** ("The Natural Moment," page 6) estimates he has taken a million photographs (see his Web site at www.artwolfe.com). His latest book, *Edge of the Earth, Corner of the Sky,* showcases Wolfe's landscape photography, with essays by Art Davidson. Wolfe made his photograph of the northern lights in Alaska under the midnight light of a half moon in March.

Trained as both a research astronomer and an attorney, **DONALD GOLDSMITH** ("Bolts from Beyond," page 28) devoted himself to popularizing astronomy thirty years ago. Since then he has written more than twenty books and collaborated on many PBS television programs on astronomy, including the 1991 series *The Astronomers*. In 1995 he was awarded the American Astronomical Society's Annenberg Foundation Prize for outstanding contributions to science education through astronomy. He lives in Berkeley, California.



"I've always been interested in life in the sea—past, present, and future," says naturalist, author, and artist **RICHARD ELLIS** ("Terrible Lizards of the Sea," page 36). His story in this issue on mosasaurs, a formidable group of extinct marine lizards, is adapted from his new book, *Sea Dragons: Predators of the Prehistoric Oceans* (University Press of Kansas). His other recent books include *The Empty Ocean* and *Aquagenesis: The Origin and Evolution of Life in the Sea*. Ellis is a research associate in paleontology at the American Museum of Natural History in New York.

Photographer and botanist **DICCON ALEXANDER** ("Splendid Isolation," page 42) is a scientific associate in the botany department of the Natural History Museum in London. Since 1994 he has done extensive work with a team from the Royal Botanic Garden in Edinburgh, Scotland, documenting the unique flora of the Socotra archipelago.

G. JEFFREY TAYLOR ("Moonstruck," page 46) is a research professor in the Hawai'i Institute of Geophysics and Planetology at the University of Hawai'i in Honolulu. His primary interest is planetary evolution, focusing on the role of magmatism and impacts in the history of the Moon, Mars, Mercury, and the asteroids, as well as on the role of aqueous alteration processes on Mars. He is the author of more than 140 refereed articles. He and Linda Martel, an associate at the institute, also publish an online popular science magazine, *Planetary Science Research Discoveries* (www.psrd.hawaii.edu).

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Who Minds the Store?

The two discussions of the looting and destruction of Iraq's precious ancient artifacts—"Lost Time," by John Malcolm Russell, and "Aftershocks," by David Keys [6/03]—are a wake-up call about the folly of retaining world-class antiquities in their third-world countries of origin. Only in the great museums and universities of the first world can irreplaceable antiquities be properly conserved and studied.

Expropriation of antiquities from a place like Iraq, where the population has been subjected to despotism and has no connection with the ancient culture under its feet, is the most suitable solution.
John B. Bute
El Lago, Texas

"I can't understand why he has to go ashore to look for bugs."

David Keys seems to blame the damage done to Iraq's archaeological heritage on the lack of military intervention. As both a veteran and a scientist, I'd like to ask how many American or Iraqi lives it would have been worth losing to safeguard the museums and their artifacts.

If we had used our limited resources to protect the cultural assets of Iraq, what else might have been destroyed? Certainly the destruction was a tragedy, but to blame the military for the results of civil disorder is unreasonable.

Much of the looting seems to have been well planned and executed. Why didn't the Iraqis do more to protect their treasures? And shouldn't they take at least some responsibility for the lawlessness?
Michael J. Everhart
Derby, Kansas

John Malcolm Russell replies: Both letters raise issues that have been the subject of much debate.

Although the tradition of the victor expropriating the art of the vanquished—a tradition Mr. Bute seems to advocate—goes back to Mesopotamia, this practice is no longer fashionable, and is prohibited by the 1954 Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict. Art is not necessarily safer in first-world countries: major paintings in Germany were destroyed during the Second World War, and several hundred works by the sculptor Auguste Rodin were lost when the offices of Cantor Fitzgerald were destroyed during the 9/11 attack.

As an alternative to expropriation, the former Ottoman practice of dividing excavated finds between the host country and the foreign institution sponsoring the excavations reduces the risks associated with having all your eggs in one basket. Host countries might consider reinstituting such a practice—with the understanding that divisions could be negotiated as open-ended loans rather than as gifts—but only if collectors and certain museums in the first world stop financing the plunder of archaeological sites.

Mr. Everhart correctly blames the looting on the looters, but it is unrealistic to eliminate a police force and then hope that criminals will no longer commit crimes. No one argues that anybody should have been placed in mortal jeopardy to protect the museum, but would guarding it have been that dangerous? Major armed resistance around the museum ended on April 9, the museum was looted on April 10–11, the staff began returning on April 12, and the United States posted guards at the building on April 16. Did the military consider protection of the museum to be a high priority it could not safely fulfill prior to April 16? Or was it unconcerned about the museum until the media and Secretary of State Colin Powell compelled it to take action? Only an independent investigation can provide answers to such questions.

Strategic Waters

I found the review by Sandra Postel ["Hydro Dynamics," 5/03] of Robert Kandel's and Diana Raines Ward's books on the nature and scarcity of freshwater to be extremely poignant. At the moment I am sitting beside the Shatt al Hillah, a river within just miles of the Euphrates. The importance of freshwater in this region is impossible to miss.

Today's decisions on the distribution and use of water will ripple through decades, if not centuries, of human interaction. The availability of water in the Middle East is a particularly thorny problem. Constructing one or two state-of-the-art desalination plants on the Mediterranean along the Gaza Strip would lessen the Palestinians' reliance on Israeli-controlled water. Large plants might even provide the Palestinians with a marketable product. For the Palestinians to have the capacity to sell water in excess of their needs, particularly to Israel, would establish a commodity exchange far more valuable than the cheap labor that now daily crosses the borders.

Given the political will,

the U. S. could negotiate donations from the many Arab countries that bemoan the plight of the Palestinian people yet offer little in the way of long-term economic solutions. Helping to build a viable Palestinian economy through the manufacture of this "artificial" natural resource would do positive things for everyone concerned.

Lt. Col. Mark L. Kimmey
U.S. Army Reserve
Humanitarian Assistance Coordination Center
Al Hillah, Iraq

Ode to the Earth

Gabrielle Walker's article on the geological epoch known as "snowball Earth" ["The Longest Winter," 4/03] shows not only her impressive knowledge of the subject but also her masterful writing style—referring to Earth's earliest organisms as "cottage industries," for instance, or describing volcanoes as being "perfectly happy to erupt under ice."

Perhaps Princeton should ask her to teach in the English department rather than the geosciences department.

Robert M. Martin Jr.
Dallas, Texas

The Joys of Fieldwork

Robert Dunn's story about army ants and their beetle "guests" ["Impostor in the Nest," 6/03] brought forth personal waves of nostalgia. As a field entomologist, I have vivid memories of pursuing butterflies in southern Mexico while dining on those same basic jelly sandwiches Mr. Dunn was eating in Costa Rica (mine, however, were made with peanut butter as well).

I was moved by his description of his fieldwork, as well as by the sense of adventure that he portrayed so well. Our techno-savvy, dot-com culture, with its "reality-based" nightly television offerings, makes many people forget that the vast majority of living things on our planet still reside in remote places, awaiting our discovery and study.

The same passion for discovery and adventure that inspired the early icons of natural history (Captain James Cook, Charles Darwin, Alfred Russel Wallace, and so on) can still be integrated into a respectable professional career by any youngster living today.

Gary Noel Ross
Baton Rouge, Louisiana

AMENDMENT: The first paragraph of Martha Hurley's reply to an enquiry concerning a photograph of the golden Vietnamese cypress ["Letters," 6/03] was intended to refer to cypresses in general. Preferable wording would have been: "The caption should have specified that for a mature cypress to bear both needles and scaly leaves on the same branch is highly unusual."

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

By Stéphan Reebs

Blowin' in the Wind

Imagine finding marine plankton drifting through thin air at 30,000 feet. That's the surprise that greeted Kenneth Sassen of the University of Alaska, Fairbanks, and his colleagues when they examined ice crystals collected by a research aircraft that had flown through cirrus clouds over Oklahoma in September 1997. A recent paper by Sassen and his co-authors shows numerous images of variously shaped crystals with cell-like structures embedded in them.

The clouds were remnants of Hurricane Nora, which had originated in the Pacific Ocean, swept up Mexico's Baja Peninsula, and slowed to a tropical storm over the U.S. Southwest. The investigators think Nora's high winds whipped up droplets of seawater and then lofted the droplets, along with their resident plankton, to the top of the troposphere. From there the plankton blew far overland to the east, all the while serving as nucleation points for some of the ice crystals that formed in the clouds. ("Midlatitude cirrus clouds derived from Hurricane Nora: A case study with implications for ice crystal nucleation and shape," *Journal of the Atmospheric Sciences* 60:873–91, April 1, 2003)

Drugs from Seaweed?

Plants have no immune systems. Chemical warfare is their way of fighting pathogens and parasites: they manufacture compounds that prevent the growth of specific disease-causing microorganisms. And sometimes those compounds are effective against human pathogens as well—the basis for much pharmacological research as well as traditional medicine, and many exhortations to preserve biodiversity.

Julia Kubanek, a biochemist at the Georgia Institute of Technology in Atlanta, and her colleagues at the Scripps Institution of Oceanography in La Jolla, California, suggest that seaweed could be similarly tapped for future drugs. Marine plants literally live in a sea of bacteria, archaea, viruses, and fungi—some of which are bound to be pathogenic—yet they seldom get sick. Surprisingly little is known about seaweed's chemical defenses, but Kubanek and her team have begun to remedy that deficiency.

From the brown alga *Lobophora variegata*—a tropical seaweed especially dominant in the Caribbean—the investigators have isolated a potent new compound they call lobophorolide. In laboratory tests, small quantities of it stunted the growth of two marine fungi that cause disease in marine plants.

The alga Lobophora variegata *(greenish ruffles): apothecary of the sea?*

Nevertheless, lobophorolide had no effect on a pathogenic bacterium, and did not repel herbivorous fishes. Kubanek and her team think other compounds may pick up where this one leaves off. Algae may turn out to be underwater pharmacies, deploying a variety of medicines, each aimed at a different affliction. ("Seaweed resistance to microbial attack: A targeted chemical defense against marine fungi," *Proceedings of the National Academy of Sciences* 100:6916–21, June 10, 2003)

New Guinea's gift to the world

The Fruits of Prehistory

Agriculture began in Mesopotamia, the "cradle of civilization," right? True, but it also seems to have arisen independently in several other places as well, including China and Mesoamerica. In the 1970s some archaeologists asserted that New Guinea was one of those places. Their evidence at the time was equivocal, but now Tim Denham of Flinders University in Adelaide, Australia, and his colleagues have collected enough strong evidence to show that bananas were first farmed in the highlands of New Guinea at least 7,000 years ago.

What did they find? Numerous fossilized remains—plant crystals (of taro as well as bananas) and pollen—that complement the well-dated remains of ancient cultivation mounds and ditches. Nowadays there are hundreds of varieties of bananas; collectively they've become one of the world's most important food crops. Strange to relate, however, fruit lovers in the United States have been munching on bananas only since the nineteenth century. ("Origins of agriculture at Kuk Swamp in the highlands of New Guinea," *Science* 301:189–93, July 11, 2003)

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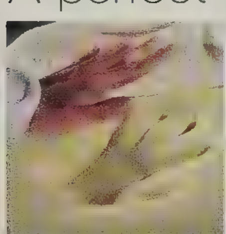

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Experiment of the Month

It isn't easy being an archaeologist. The ancient artifacts you work with are often battered and fragmentary, and you have to base a lot of your interpretations on the stratum where you find the artifacts. Given the many species of burrowing animals—which seem pretty cavalier about the effects of their excavations on scientific evidence—it seems perilous indeed to put much stock in the discovery stratum. Animals might have displaced your crucial artifacts many times before you unearthed them.

Knowing what a burrower the armadillo is—and how little attention had been paid to it—the Brazilian archaeologists Astolfo G. Mello Araujo of the University of São Paulo and José Carlos Marcelino of São Paulo's Department of Historical Patrimony decided to study the animal's effects on an experimental "dig" at the São Paulo Zoo. They spray-painted four groups of ersatz artifacts (actually ceramic shards and stone flakes) in four distinct colors and sprinkled them into four separate layers in the ground. The result was a two-foot-deep "layer cake," whose top layer of artifacts was open to the air and whose other layers were separated from one another by eight inches of earth.

Then a lone female armadillo was turned loose at the site for almost two months, after which the archaeologists surveyed the

Six-banded armadillo (Euphractus sexcinctus), *the archaeologist's helper?*

thoroughly mucked-up earth. The effects were easy to see: blue objects pushed many inches up to the yellow ones, yellows pushed down among the blues, big and small items both dislodged. Fortunately, though, the concentration of objects from a given stratum still peaked near their original level.

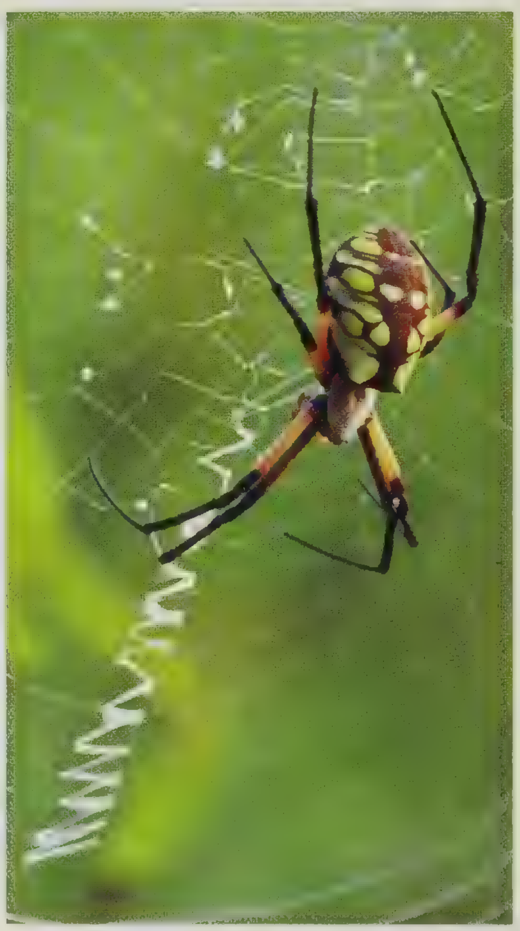
One possible benefit of this kind of "noise" in the archaeological signal is that by bringing artifacts to the surface, armadillos can help archaeologists locate promising sites for their own, more systematic digging. ("The role of armadillos in the movement of archaeological materials: An experimental approach," *Geoarchaeology* 18:433–60, 2003)

Love and Death

In North America, if you see a classic spiderweb with a dense, zigzag thread through its center, the web could well have been spun by *Argiope aurantia*. Even more striking than the web, though, is the species' sexual politics: for the male, copulation is suicide.

Other male spiders die during mating, but that's because the females kill and eat them. Evolutionary biologists Matthias W. Foellmer of Concordia University in Montreal and Daphne J. Fairbairn of the University of California, Riverside, have now determined that in *A. aurantia* the males themselves are programmed to undergo sudden death—attacked or not.

Whether his partner is a defenseless, molting juvenile or a consenting though potentially aggressive adult, the male goes into his death throes within moments of inserting the second of his two pedipalps (mating appendages) inside the second of the female's two genital apertures. Once that pedipalp inflates, it's curtains for the guy. Within fifteen minutes—and



Object of desire: A female yellow garden spider (Argiope aurantia)

usually sooner—his heart stops, even when the female is prevented (by experimenters) from molesting him. A further bit of proof that death occurs without female complicity: one male, after inserting his first pedipalp in the normal place, moved elsewhere on the female's web and inexplicably inserted his second pedipalp into a nearby dead mealworm. He died instantly—and not of shame at his mistake.

What could be the evolutionary advantage of dying just after mating? Foellmer and Fairbairn speculate that, because most mating is opportunistically imposed on defenseless juvenile females, the dead male may act as a "mating plug"—a kind of temporary, organic chastity belt—to prevent other males from having their turn. ("Spontaneous male death during copulation in an orb-weaving spider," *Proceedings of the Royal Society of London* B (Suppl.), DOI 10.1098/rsbl.2003.0042, 2003)

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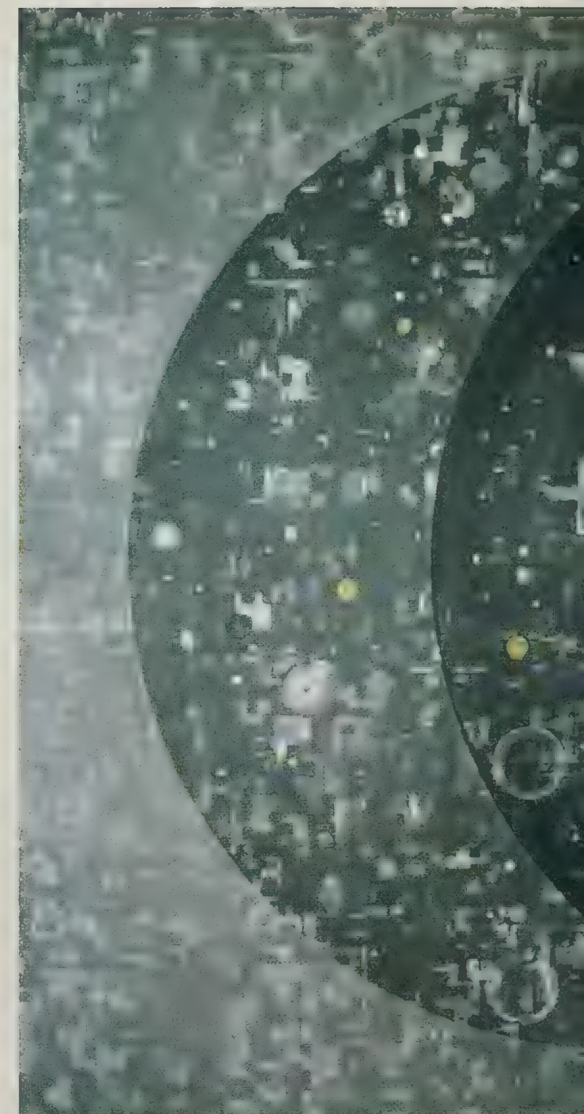
In the Beginning

Back in the olden days—the first trillionth of a second after the big bang—energy was matter, matter was energy, and $E=mc^2$ *ruled.*

By Neil deGrasse Tyson



Physics describes the behavior of matter, energy, space, and time, and how the forces of nature enable their interplay. From what scientists have been able to determine, all biological, chemical, and physical phenomena emerge from how four, and only four, forces push and pull the contents of the universe. But is that all there is?

In almost any area of scientific inquiry—but particularly in physics—the frontiers of discovery live at the extremes of measurement. At the extremes of matter, such as the neighborhood of a black hole, you find gravity (one of the four forces) badly warping the surrounding fabric of space-time. At the extremes of energy, you sustain thermonuclear fusion in the ten-million-degree cores of stars (where the attraction of the strong nuclear force overwhelms the repulsion of the electromagnetic force). And at every extreme imaginable, you get the outrageously hot, outrageously dense conditions that prevailed during the first few moments of the universe.

Daily life, I'm happy to report, is entirely devoid of extreme physics. On a normal morning, you get out of bed, wander around the house, eat something, dash out the front door. And by day's end, your loved ones fully expect you to look no different than you did when you left, and to return home in one piece. But imagine arriving at the office, walking into an overheated conference room for an important 10 A.M. meeting—and suddenly losing all your electrons. Or worse yet, having every atom of your body fly apart. Or suppose you're sitting in your office trying to get some work done by the light of your desk lamp, and somebody flicks on the overhead light, causing your body to ricochet from wall to wall until you're jack-in-the-boxed out the window. Or what if you go to a sumo wrestling match after work and see the two spherical gentlemen collide, disappear, then spontaneously become two beams of light?

If that kind of scene played itself out daily, modern physics wouldn't look so bizarre, knowledge of its foundations would flow naturally from life experience, and our loved ones probably would never let us go to work. But back in the early minutes of the universe, those antics happened all the time. To envision that era, and understand it, one has no choice but to establish a new form of common sense, an altered intuition about how physical laws apply at the extremes of temperature, density, and pressure.

Enter the world of $E=mc^2$.

Einstein first published a version of his famous equation in 1905, in a seminal research paper titled "On the Electrodynamics of Moving Bodies." Better known as the special theory of relativity, the concepts advanced in that paper forever changed the understanding of space and time. Einstein, then just twenty-six years old, offered further details about his tidy equation in a separate, remarkably short paper published later that year: "Does the Inertia of a Body Depend on Its Energy-Content?" To save you the effort of digging up the original article, designing an experiment, and testing the theory, the answer is "Yes." As Einstein wrote,

> If a body gives off the energy E in the form of radiation, its mass diminishes by E/c^2. . . . The mass of a body is a measure of its energy-content; if the energy changes by E, the mass changes in the same sense. . . .

Sensibly cautious about the truth of his statement (it was a theoretical prediction, after all), he then suggested:

Gregory Gioiosa, *Tri-Composition of Existential Time*, 1995

It is not impossible that with bodies whose energy-content is variable to a high degree (e.g. with radium salts) the theory may be successfully put to the test.

There it is: the algebraic recipe for all occasions when you want to convert matter into energy or energy into matter. In those simple sentences Einstein unwittingly gave astrophysicists a computational tool, $E=mc^2$, that extends their reach from the universe as it now is, all the way back to infinitesimal fractions of a second after its birth.

The most familiar form of energy is the photon, a massless, irreducible particle of light. You are forever bathed in photons: from the Sun, the Moon, and the stars, to your stove, your chandelier, and your night light. So why don't you experience $E=mc^2$ every day? The energy of visible-light photons is far less than the amount of energy that is equivalent to the mass of the least massive subatomic particles. There is nothing else those photons can become, and so they live happy, though boring, lives.

Want a little action? Start hanging around gamma-ray photons that have some real energy—at least 200,000 times more than that of visible photons. You'll quickly get sick and die of cancer, but before that happens, you'll see something truly weird. Matter-antimatter pairs of electrons—one of the many dynamic duos in the particle universe—pop into existence where photons once roamed. Yes, energy turns into matter. Then, as you watch, you'll see some of the matter-antimatter pairs of electrons collide, annihilating each other and creating gamma-ray photons once again. And yes, matter turns back into energy. It all happens according to $E=mc^2$.

Increase the gamma rays' energy by a factor of another 2,000, and you still have gamma rays—but now with enough energy to turn susceptible people into the Hulk. Furthermore, pairs of these potent photons now have enough energy to spontaneously create much more massive particles: neutrons, protons, and their antimatter partners.

The cosmological significance of particles and photons transmuting into each other is staggering. The background temperature of our expanding universe, calculated from measurements of the microwave bath of light that pervades all of space, is a very chilly 2.73 degrees Kelvin—455 degrees below zero Fahrenheit. Yesterday, though, the universe was a little bit hotter, and a little bit smaller, than it is today. The day before, it was hotter and smaller still. Roll the clocks backward some more—say, 13.7 billion years—and you land squarely in the primordial soup of the big bang.

The way space, time, matter, and energy interacted as the universe expanded and cooled from the beginning is one of the greatest stories ever told. But to explain what went on in that cosmic crucible, you must find a way to merge the four forces of nature into one. That challenge includes finding a way to reconcile two incompatible branches of physics: quantum mechanics (the science of the small) and general relativity (the science of the large).

Although physics hasn't yet reached that finish line, physicists know exactly where the stumbling blocks are: they all pile up during the "Planck era"—so named for the German physicist Max Planck, who fathered quantum mechanics in 1900. The Planck era began with the big bang and ended 10^{-43} second later (that's one ten-million-trillion-trillion-trillionth of a second); in that unimaginably short time the universe grew to

10 meter (one hundred-billion-trillion-trillionth of a meter) across.

Not to worry, though. The clash between gravity and quantum mechanics poses no practical problem for the contemporary universe. Astrophysicists apply the tenets and tools of general relativity to problems very different from the ones normally encountered in quantum mechanics. But in the beginning, during the Planck era, the known universe was a lot smaller than an atomic nucleus, and so there must have been a kind of shotgun wedding between the large and the small. Alas, the vows exchanged during that ceremony continue to elude us all; no known laws of physics describe the universe with any confidence during what was surely the briefest marriage in history.

At the end of the Planck era, gravity wriggled loose from the other, still-unified forces of nature, taking on its familiar independent identity. As the universe aged by a factor of a hundred million to the venerable age of 10^{-35} second, it continued to expand and cool. What remained of the unified forces split into the electroweak and the strong nuclear forces. Later still, the electroweak force split into the electromagnetic and the weak nuclear forces, laying bare the four distinct forces we have come to know and love. Today the weak force controls some kinds of radioactive decay, the strong force holds the nucleus together, the electromagnetic force binds molecules, and gravity operates on bulk matter. And all those forces had established their independence by the time the universe was a mere trillionth (10^{-12}) of a second old.

All the while, the interplay of matter and energy was incessant. Shortly before, during, and after the strong and electroweak forces parted company, the material universe was a seething ocean of quarks, leptons, their antimatter siblings, and bosons, which are particles that convey the various forces. None of the particles belonging to these families is thought to be divisible into anything smaller or more basic.

Fundamental though they are, each family of particles comprises several species. The boson family includes the ordinary visible-light photon. The most familiar leptons (to the nonphysicist, anyway) are the electron and perhaps the neutrino. And the most familiar quarks are . . . well, there are no familiar quarks. Each species has been given an abstract name that serves no real philological, philosophical, or pedagogical purpose except to distinguish it from the others: up and down, strange and charm, and top and bottom.

Galaxies, planets, and people owe their existence to a trifling primordial imbalance of matter and antimatter.

Quarks are quirky beasts. Unlike the more familiar proton, which has an electric charge of plus-one, or the electron, which has a charge of minus-one, quarks have fractional electric charges that come in thirds. And you'll never catch a quark all by itself; it will always be clutching on to other quarks nearby. In fact, the force that keeps two or more of them together actually grows stronger the more you try to pull them apart—as if they were connected by some kind of subatomic rubber band. If you pull a couple of quarks far enough apart, the rubber band snaps and the stored energy summons $E=mc^2$ to create a new quark on each end of the break, leaving you with quark pairs once again.

But during the era of seething quarks and leptons the universe was so dense, and the average separation between quarks was so small, that it doesn't make any sense to say whether quark pairs were attached or not. Under those conditions, an allegiance between adjacent quarks could not be unambiguously established. In spite of being collectively bound, they moved freely among themselves, like ingredients in a quark soup.

Strong theoretical evidence suggests that an episode in the very early universe, perhaps during one of the force splits, endowed the universe with a slight but remarkable asymmetry: for every billion and one particles of matter, there were a billion particles of antimatter. That small difference hardly got noticed amid the continuous creation, annihilation, and re-creation of quarks and antiquarks, electrons and antielectrons (better known as positrons), and neutrinos and antineutrinos. The odd man out always had plenty of chances to find someone to annihilate with.

But not for much longer.

As the cosmos continued to expand and cool, it grew to the size of the solar system, and its temperature dropped below a trillion degrees Kelvin. A millionth of a second had passed since the beginning.

That "tepid" universe was no longer hot enough or dense enough to cook quark soup, and so the quarks all grabbed dance partners, creating a permanent new family of heavy particles called hadrons. Among the hadrons were protons and neutrons as well as other, less familiar heavy particles, all made up of various combinations of quarks. The slight matter-antimatter asymmetry afflicting quarks and leptons now got passed to the hadrons, but with extraordinary consequences.

As the universe continued to cool, ambient photons could no longer invoke $E=mc^2$ to manufacture hadron-antihadron pairs. Not only that, when hadrons and antihadrons met and annihilated, the energy of the resulting photons diminished in the ever-expanding universe, dropping below the threshold required to create new hadron-antihadron pairs. For every billion annihilations—leaving a billion photons in their wake—a single hadron survived. Those loners would

ultimately get to have all the fun: serving as the building blocks of galaxies, stars, planets, and people.

Without the billion-and-one-to-a billion imbalance between matter and antimatter, all mass in the universe would have annihilated, leaving a cosmos made of photons and nothing else—giving fresh meaning to the phrase "Let there be light."

By now, one second has passed since the beginning of time.

The universe has grown to a few light-years across. At a billion degrees, it's still plenty hot—and still able to cook up electrons and positrons, which continue to pop in and out of existence. But in the expanding, cooling universe, their days (seconds, really) are numbered. What was true for hadrons is true for electrons: the expansion makes annihilation a one-way trip, and eventually only one electron in a billion survives.

When the cosmic temperature drops below a hundred million degrees, protons and neutrons fuse to form atomic nuclei, of which 90 percent are hydrogen, and 10 percent are helium and trace amounts of deuterium, tritium, and lithium.

Two minutes have passed since the beginning.

Not for another 380,000 years does much happen to the primordial soup. Throughout those millennia the temperature remains hot enough for electrons to roam free among the atomic nuclei, batting them to and fro. But all this freedom comes to an abrupt end when the temperature of the universe falls below 3,000 degrees Kelvin (about half the temperature of the Sun's surface). Right about then, the electrons combine with all the free nuclei, leaving behind a ubiquitous bath of visible-light photons, and completing the formation of particles and atoms in the infant universe.

As the universe continues to expand, its bath of photons continues to lose energy, dropping from visible light to infrared to microwaves. And today, everywhere astrophysicists look, they find an indelible fingerprint of 2.73-degree microwave photons, whose pattern on the sky retains the memory of the distribution of matter just before atoms formed. From that, cosmologists can deduce many things, including the age and shape of the universe.

But what happened before all this? What happened before the beginning?

Astrophysicists have no idea. Or, rather, our most creative ideas have little or no grounding in experimental science. Yet I have found that many religious people tend to assert, with a tinge of smugness, that something must have started it all: a force greater than all others, a prime mover. In the mind of such a person, that something is, of course, God.

But what if the universe was always there, in a state or condition we have yet to identify—a multiverse, for instance? Or what if the universe, like its particles, just popped into existence?

I'll grant that such replies satisfy nobody. Nevertheless, they remind us that ignorance is the natural state of mind for a research scientist on the ever-advancing frontier. People who believe they are ignorant of nothing have neither looked for, nor stumbled upon, the boundary between what is known and unknown in the cosmos. And therein lies a fascinating dichotomy. "The universe always was" seldom gets recognized as a legitimate answer to "What was around before the beginning?"—even though for many religious people, the statement "God always was" is the obvious and pleasing answer to "What was around before God?"

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City. Videotapes of a dozen of his lectures, under the title "My Favorite Universe," were recently released by the Teaching Company (www.techco.com). *All twelve are based on essays that have appeared in* Natural History.

The Pleasure (and Pain) of "Maybe"

Both tease and terrorist exert control by fostering uncertainty in their targets.

By Robert M. Sapolsky

Then there was the summer Jonathan spent unsuccessfully wooing Rebecca. Both were savanna baboons living in the Serengeti Plains in East Africa, part of a troop I've been studying intermittently for twenty-five years. Jonathan was a gangly juvenile that had recently joined the troop; Rebecca was the confident young daughter of one of the highest-ranking matriarchs. Jonathan had taken one look at Rebecca and developed a god-awful male baboon crush that had him loping around after her wherever she went.

What he was probably after was to get her to groom him, or maybe even to coax her into something more intimate. What he was willing to settle for was a chance to groom her. But Rebecca was having none of it; she hardly acknowledged his existence. Whenever she'd sit down in the shade, or hang out with some friends, there was Jonathan, eager to groom her—and almost invariably getting the cold, fur-covered shoulder.

Olivia Parker, *Wheel of Uncertainty*, 1995

By all logic, such spectacular lack of success should have made Jonathan give up, or, as a psychologist might put it, should have caused "the behavior to extinguish." But eventually Rebecca became a little less resistant, and then, every so often, perhaps once a week, she gave in to his dogged devotion and let him groom her. Once she even groomed him back for a few distracted seconds, leaving him in baboonish ecstasy.

And that was all it took. Aglow from these crumbs of attention, poor Jonathan would redouble his efforts for the next few days.

The whole soap opera frustrated me enormously. I was working alone out in the middle of nowhere, probably badly in need of some "social grooming" myself, and clearly identifying with Jonathan. I sublimated Jonathan's predicament into grand orations in my head: "Here are the primate roots of our magnificent human capacity for gratification postponement. Here, in this pathetic dork of a baboon and his willingness to keep trying again and again despite a pitiful success rate, is the key to human greatness. Here is the suitor who keeps up a fifty-year courtship, the obsessive who spends a decade constructing a life-size replica of Elvis out of bottle caps. Here's all of us who forwent immediate pleasure in order to get good grades in order to get into a good college in order to get a good job in order to get into the nursing home of our choice."

What is it that gives us the power to do the harder thing, to be disciplined and opt for delayed gratification? And why is the rare, intermittent reward, the hint that you might win the lottery, so compelling? Two recent studies—one published in the journal *Nature*, the other in the journal *Science*—go a long way toward explaining

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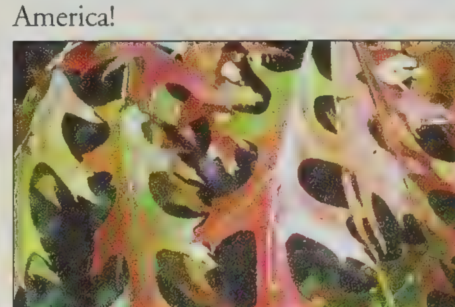


these mysteries. But before considering those reports, it's worth taking a brief tour through some parts of the brain that play a key role in the story.

The starting point of the tour is the frontal cortex, a region that takes up a much larger proportion of the primate brain than it does in other animals. The frontal cortex plays a big role in executive control, delayed gratification, and long-term planning. It does so by keeping the limbic system in check, primarily through neural projections that can release an inhibitory neurotransmitter into that deeper, more ancient brain system that specializes in emotion and impulsivity. Furthermore, the frontal cortex excels at resisting stimulating inputs from the limbic system: "Screw studying for the exam; run amok instead."

People with tight, regimented, "repressive" personalities have elevated metabolic rates in the frontal cortex, whereas sociopaths have lower-than-normal ones. If a person's frontal cortex is accidentally destroyed, he or she becomes a "frontal" patient—sexually disinhibited, hyperaggressive, socially inappropriate. With all that going for it, the frontal cortex is the closest thing we have to a neural basis for the superego.

But just what is it that gives the frontal cortex the backbone to ignore the siren call of the limbic system? There has long been evidence that a projection or conduit into the frontal cortex from a brain region called the ventral tegmentum plays a major role. This conduit serves as a Doctor Feelgood, dispensing doses of dopamine, a neurotransmitter closely associated with pleasure. Drugs such as cocaine increase the dopamine signal along this pathway, which is one reason they are so popular. Animals rigged up to get an electrical charge through the ventral tegmentum will work like maniacs, pressing levers, forgoing every earthly pleasure offered to them, in order to get the stimulus.

So when is dopamine released? For a long time the answer seemed obvious: right after getting something highly desirable, a reward. Suppose you've implanted electrodes in a monkey's brain that enable you to monitor when the dopamine pathway gets activated. Sure enough, if you give the monkey some great reward from out of nowhere, you'll see a burst of activity: dopamine bathing the monkey's frontal cortex.

But in a series of studies in the mid-1990s, Wolfram Schultz, a neuroscientist then at the University of Fribourg in Switzerland, did some critical studies that threw that simple picture into disarray. Schultz trained monkeys to perform simple tasks to gain a reward. For example, if an animal pressed the correct lever, after a few seconds' delay it would get a bit of some desirable food. There was one special condition: a light would come on, signaling to the monkey that it could now begin its task. One might predict that the dopaminergic pathway would be activated after that food reward was received. But that's not what happened. The activity peaked right after the light came on, before the monkey performed its task.

"A relationship," a cynical friend used to say, "is the price you pay for the anticipation of it."

In this context, the pleasurable dopamine isn't about reward. It's about anticipating the reward. It's about mastery and expectation and confidence. ("I know what that light means; I know the rules: *if* I press the lever, *then* I'm going to get some food. Hey, I'm all over this. This is going to be great.")

Psychologists refer to the period of anticipation, of expectation, of working for reward as the "appetitive" stage; the stage afterward, which commences with reward, they call the consummatory stage. Schultz's findings show that if you know your appetites are eventually going to be sated, pleasure is more about the appetite than about the sating. I am reminded of the cynical observation of a classmate in college, a person with a long string of disastrous relationships. "A relationship," he used to say, "is the price you pay for the anticipation of it."

Well, how about that? We've just sorted out the neurochemistry of putting up with thirty-year mortgages. All you need to do is train for longer and longer intervals between light and reward, and those anticipatory bursts of dopamine will fuel increasing amounts of lever pressing, or monthly payments.

One of the two recent studies I alluded to earlier fills in a critical gap in this story. Writing in the 10 April 2003 issue of *Nature,* Paul E. M. Phillips and his colleagues from the University of North Carolina, Chapel Hill, tell how they have measured bursts of dopamine in rats down to the millisecond. They have shown that the burst comes just before the behavior. And here's the clincher: when they artificially stimulated the dopamine release (rather than letting the light cue trigger it), the rat suddenly started pressing the lever. The dopamine fuels the behavior.

How might these findings apply to the savanna soap opera of Jonathan and Rebecca? There he sits, dozing in the equatorial sun. Rebecca appears in the distance (dramatic entrance at the other end of the field, wind-swept fur, the whole deal). Jonathan's appetitive light goes on, and his ventral tegmentum gets all hyperactive and releases dopamine like mad. This gives his frontal cortex the impetus to do the harder thing, to resist the easy out of just sitting there in his midday torpor. Instead, he gets up and walks across that endless field, powered by the anticipatory certainty (Wagner now in the background) that she is going to let him groom her.

But logically, Jonathan should react this way only if there's a tightly coupled *if-then* clause guiding his relationship with Rebecca. (If I show certain behavior, then I will get a reward.) But there isn't any such certainty. There's an *if-maybe.* Jonathan pursues Rebecca, but it only works some of the time. And yet that is enough to keep him reinforced, or motivated. Why does Rebecca's coyness work? Why does "intermittent reinforcement" seem so much more enticing than a sure thing?

In the second paper, published in the 21 March 2003 issue of *Science,* the neuroscientist Christopher D. Fiorillo of the University of Cambridge and his colleagues (one of whom is Schultz) addressed that question with a brilliant experiment, once again with monkeys. Back to the laboratory setup: Light comes on, press lever, get the reward a few seconds later. Now add the Jonathan-Rebecca component, *maybe:* Light comes on, press lever, get the reward—but only, on average, 50 percent of the time. Right on the fulcrum of uncertainty, maybe yes, maybe no. Now what happens to the dopamine activity?

Remarkably, it increases. And even more remarkable is the way it does so: Light comes on, and there's the usual dopamine rise, fueling the lever pressing. Then, lever pressing completed, a second phase of dopamine release begins, gradually increasing until it peaks right around the time the reward would normally occur.

Suppose the experimenters decrease the degree of uncertainty, of unpredictability: Light comes on, lever is pressed, but now there's only a 25 percent chance of reward. Or make it 75 percent. Of course, 25 percent and 75 percent are opposite trends in the chances of reward, but they do have one thing in common: they carry less of a *maybe* than the 50 percent scenario. What happens? The secondary rise in dopaminergic activity takes place, but to a smaller extent. The most dopamine is released when the uncertainty is greatest.

This finding explains why intermittent rewards can be so profoundly reinforcing. And the experimental findings dovetail nicely with the literature in the physiology of stress, which reveals the dark side of *maybe:* a punishment with a fair chance of occurring can be vastly more stressful than a predictable one. When the infliction of punishment is unpredictable, stress-hormone levels and blood pressure are likely to rise, and the risk of stress-related disease rises, too. Joan Silk, a primatologist at the University of California, Los Angeles, has presented evidence that one of the skills honed by alpha-male baboons to keep the competition off kilter is to be brutally aggressive at times in utterly random, unpredictable ways. The corrosive core of terrorism, too, is the orange-alert world of never knowing where or when.

The research by Fiorillo and his colleagues may also help explain why the chance of a huge reward, even the most ludicrously remote *maybe* of a chance, can be so addictive, spiraling wild-eyed gamblers into squandering the kids' food money at the casino. That gleaming calculator of a cortex sits there marinating in all sorts of frothy, hormonal, affective influences, which can make so-called rational assessments end up as pretty irrational. That's why, if the lottery payoff is big enough, we become convinced—no matter what the odds against it—that we've got the lucky number and that we're soon going to be in social-grooming heaven.

And Jonathan and Rebecca? Well, she remained more interested in the high-ranking, prime-age guys, and he eventually got over his crush. A few years later, though, they had one wild twenty-four-hour fling, on a day that she was at the peak of her ovulatory cycle. But that's another story.

Robert M. Sapolsky is a professor of biological sciences and neurology at Stanford University. His most recent book is A Primate's Memoir: A Neuroscientist's Unconventional Life among the Baboons.

Squeeze Play

Brobdingnagian earthmoving "worms" dig their tunnels with a hydraulic ram.

By Adam Summers ~ Illustration by Roberto Osti

When I first saw a live caecilian, I was convinced that I was looking at an earthworm large enough to strike fear in the heart of an Alabama largemouth bass. The animal squirming through the sphagnum moss was *Dermophis mexicanus,* a Central American species of amphibian that reaches two feet in length and is as fat around as the most decadent Cuban cigar. Like common earthworms, caecilians' brown-gray bodies sport closely spaced, circumferential grooves; the animals' blunt heads bear a striking resemblance to their tails, their eyes are quite small, and they lack arms and legs. If you were to grasp one in your hand, it would squirm like a healthy night crawler trying to escape the hook.

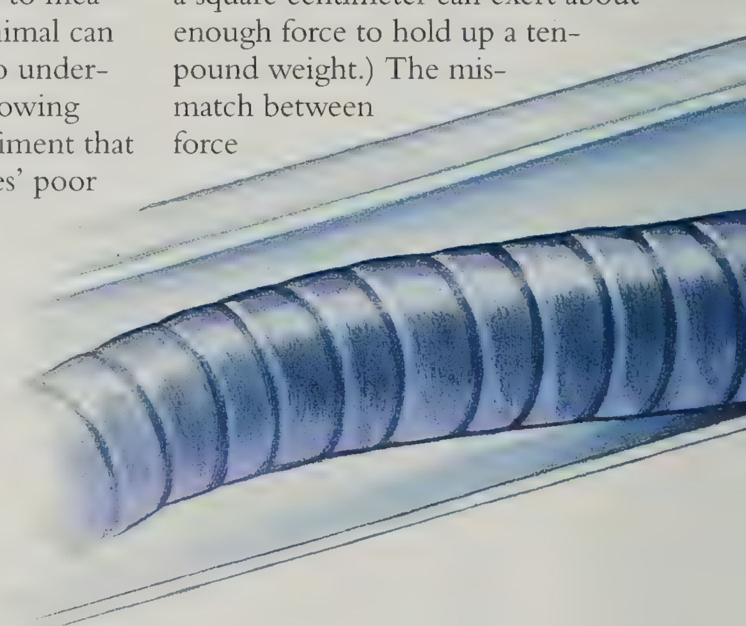
But such a scene is about as likely as latching onto a fifty-pound bass. Caecilians so seldom have contact with people that most species have no common name. Although they are amphibians, caecilians are denizens of the terrestrial underworld. (One odd species, the atypically aquatic *Typhlonectes natans,* can be bought in pet stores, albeit under the misleading name "rubber eel.") Anyone hoping to find one should bring a shovel to the world's humid tropics.

As you dig, however, you'll quickly be reminded that burrowing is tough. The short, stout arm bones of moles and armadillos reflect the extreme demands of tunnel excavation, as do the thick, reinforced skulls of other burrowing vertebrates, such as the caecilians. Those animals have abandoned limbs altogether in favor of slicing through the earth with their narrow bodies.

Like digging, studying the mechanics of burrowing is also tough, because, well, it happens underground. Nevertheless, James C. O'Reilly, a biomechanist at the University of Miami in Florida, has managed the task, and in the process has discovered that caecilians such as *D. mexicanus* not only look like worms, they move like them.

A caecilian faces one primary constraint as it burrows through the ground: the hardness of the soil. So if you want to understand how fast and through what kinds of soil a caecilian can move, the critical factor to measure is how forcefully the animal can manage to ram the earth. To understand the mechanics of burrowing O'Reilly designed an experiment that took advantage of the species' poor eyesight. Laboratory animals were fooled into "burrowing" into a clear acrylic tube with a ninety-degree bend. Beyond the bend, a second tube, filled with soil and connected to a sensitive force gauge, was set inside the first. When a caecilian encountered the soil-filled tube, the animal would push against the soil as hard as it could, seeking to escape the alien environment of the artificial burrow. And as hard as it could push, it turns out, was much harder than what O'Reilly had expected.

D. mexicanus burrows by straightening its vertebral column and ramming its head into the dirt. (The action is not unlike pushing a tent peg into the ground.) Large bundles of muscle that can move the vertebral column line both sides of the caecilian's spine. The muscles obviously contribute to burrowing, but their cross-sectional area can account for only about a quarter of the pushing force. (As regular readers of this column may recall, the potential force a muscle can generate depends directly on its cross-sectional area. A muscle with a cross section of a square centimeter can exert about enough force to hold up a ten-pound weight.) The mismatch between force



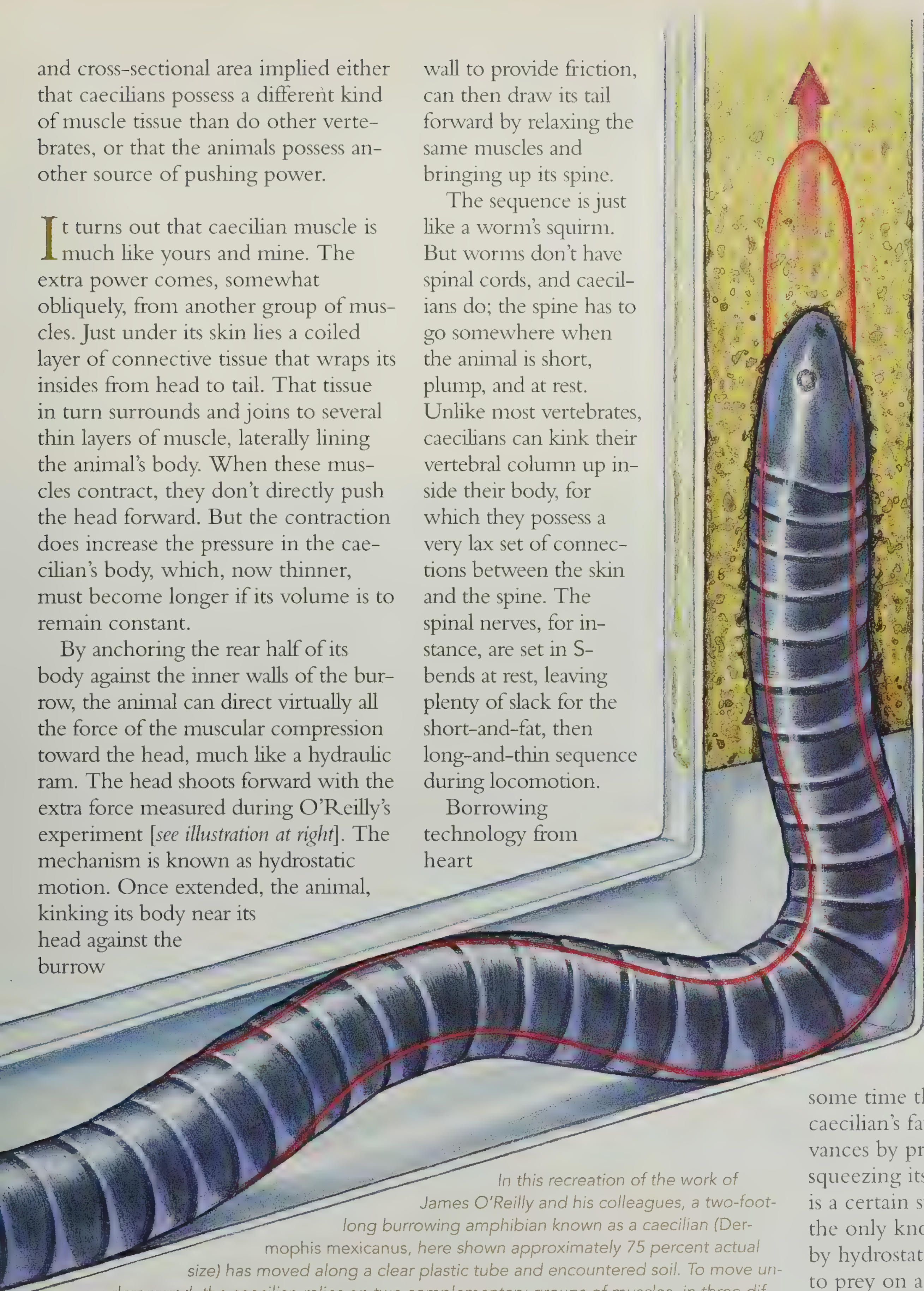
and cross-sectional area implied either that caecilians possess a different kind of muscle tissue than do other vertebrates, or that the animals possess another source of pushing power.

It turns out that caecilian muscle is much like yours and mine. The extra power comes, somewhat obliquely, from another group of muscles. Just under its skin lies a coiled layer of connective tissue that wraps its insides from head to tail. That tissue in turn surrounds and joins to several thin layers of muscle, laterally lining the animal's body. When these muscles contract, they don't directly push the head forward. But the contraction does increase the pressure in the caecilian's body, which, now thinner, must become longer if its volume is to remain constant.

By anchoring the rear half of its body against the inner walls of the burrow, the animal can direct virtually all the force of the muscular compression toward the head, much like a hydraulic ram. The head shoots forward with the extra force measured during O'Reilly's experiment [*see illustration at right*]. The mechanism is known as hydrostatic motion. Once extended, the animal, kinking its body near its head against the burrow wall to provide friction, can then draw its tail forward by relaxing the same muscles and bringing up its spine.

The sequence is just like a worm's squirm. But worms don't have spinal cords, and caecilians do; the spine has to go somewhere when the animal is short, plump, and at rest. Unlike most vertebrates, caecilians can kink their vertebral column up inside their body, for which they possess a very lax set of connections between the skin and the spine. The spinal nerves, for instance, are set in S-bends at rest, leaving plenty of slack for the short-and-fat, then long-and-thin sequence during locomotion.

Borrowing technology from heart surgeons, O'Reilly and his colleagues, David Carrier of the University of Utah in Salt Lake City and Dale Ritter at Brown University in Providence, Rhode Island, implanted miniature pressure gauges, smaller than a grain of rice, into the body cavities of several caecilians. The pressure peaked, they discovered, at the same time as the forward force did, confirming their hydrostatic-motion hypothesis. Thus what a caecilian does while burrowing is more like driving a steam piston into the ground than pounding a tent stake. Furthermore, when the animal was prevented from sealing its single lung—thus preventing the pressure of the muscles from being transmitted throughout the rest of the body—the caecilian's burrowing force dropped considerably.



*In this recreation of the work of James O'Reilly and his colleagues, a two-foot-long burrowing amphibian known as a caecilian (*Dermophis mexicanus*, here shown approximately 75 percent actual size) has moved along a clear plastic tube and encountered soil. To move underground, the caecilian relies on two complementary groups of muscles, in three different ways. One group controls the simple battering action of its vertebral column. The second group is connected to spirals of tendons just under the skin. When the latter muscles contract, the animal becomes thinner; because the caecilian's volume is constant, the now-squeezed animal must become longer. By anchoring itself with S-shaped kinks, the animal can apply this lengthening force in a forward direction. At the same time, the tendons (not shown), which are arranged much like the material in a "Chinese" finger trap, push on the skull, providing a third source of force. A burrowing caecilian can thereby generate more than twenty pounds of forward force. (The contracted, elongated state of the animal is outlined in red; its diameter, but not its length, is exaggerated here for clarity.)*

Biomechanists have known for some time that the earthworm (a caecilian's favorite meal) also advances by pressurizing its body and squeezing its head forward. So there is a certain symmetry to this story: the only known vertebrate to move by hydrostatic locomotion happens to prey on an invertebrate that relies on the same mechanism. What would it feel like to bait a hook with one of these animals, and reel in a fifty-pound largemouth?

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Bolts from Beyond

Some "shooting stars" come to Earth bearing secrets from other planets, as well as clues about the makeup of the solar system before the planets formed.

By Donald Goldsmith

A bolide, or particularly bright meteor, hurtles across the sky, leaving a trail that lasts for a few seconds. This lithograph appeared in 1868, in Amédée Guillemin's book The Heavens.

For two centuries, astronomers and geologists have recognized that the Earth is continually bombarded by small extraterrestrial objects called meteoroids. Each piece of this cosmic debris has its own orbit around the Sun. Because some of those orbits cross the Earth's, our planet and certain bits of the debris inevitably reach the same point at the same time and collide.

Every day, in fact, about a hundred tons of extraterrestrial material rain onto our planet, most in the form of grains of dust that float gently downward and land undetected. Some of that dust has been captured by collectors mounted on high-flying aircraft, but the great hope for obtaining significant amounts of it resides with the spacecraft *Stardust,* launched in 1999 and now on the other side of the Sun from Earth. Early in 2006 *Stardust* will return to Earth with samples of the interplanetary medium.

It is probably natural to think of meteorites—as the meteoroids that fall to Earth are called—as threatening, even dangerous, phenomena. The best-known meteorites, not surprisingly, are the ones that strike something important, perhaps one of us. Despite the impression left by Hollywood movies, however, people have been hit by meteorites only once or twice in recorded history, and those impacts led to only minor injuries. The only verified mammalian fatality from a meteorite impact in the past century was a dog unlucky enough to occupy the exact spot near Alexandria, Egypt, where a meteorite from Mars struck on a June day in 1911. Closer to home (and more typical), on October 9, 1992, a large meteorite that passed over the eastern United States in a mere forty seconds reached its ground zero in Peekskill, New York, where it demolished the rear end of an aged Chevrolet [*see "nature.net," by Robert Anderson, page 63*].

Truly large meteorites, such as the thirty-four-ton iron monster that the Arctic explorer Robert Edwin Peary brought from Cape York, Greenland, to New York's American Museum of Natural History in 1897, rank among the scarcest, and scariest, objects on Earth. Fifty thousand years ago, a meteorite the size of a house and the weight of a destroyer struck near what is now the town of Winslow, Arizona, excavating a mile-wide hole known as the Barringer Meteorite Crater. Several much larger, though highly eroded, terrestrial impact craters have also been discovered, stark reminders that an object many miles in diameter strikes the Earth every 50 million to 100 million years.

Sixty-five million years ago the best-known of those supermassive impactors blasted a crater more than a hundred miles across, centered near what is now the town of Chicxulub on the northwest coast of Mexico's Yucatán Peninsula. The incoming object raised an immense cloud of grit and dust that rose high above the atmosphere, spread around the globe like syrup on ice cream, and took months to settle back down. Because the geologic record shows that the Chicxulub impact coincided with the extinction of the dinosaurs (as well as with that of many other earthly species), most paleontologists regard it as the cause of the dinosaurs' demise. Their extinction made room for the subsequent radiation of mammals into newly vacant ecological niches.

Yet meteorites also play a much less sinister role. Sizable meteorites offer astronomers and geologists extraterrestrial fragments, free for the finding—"the poor man's space probes." In spite of the extensive alteration of their exteriors by their passage through Earth's atmosphere, those fragments nonetheless provide highly valuable samples of the early matter in the solar system.

In recent years it has also become clear that the incoming rain of meteoroids has a flip side: the much smaller, but potentially immensely significant, outflow of debris kicked into space by large impacts. A monster meteorite that strikes the Earth can shoot fragments of itself, along with terrestrial matter loosened by the impact, far out into space, adding to the swarm of meteoritic grit that already orbits the Sun. Even more important, the same process takes place on other worlds as well: the Moon, Mars, and the asteroid Vesta have all lost identifiable chunks that have made their way to Earth. Although the mass of that debris is an insignificant part of the total mass of incoming meteoroids, the recognition that matter can, and does, travel from planet to planet raises the stunning possibility that life itself, encapsulated within those bits of rock, might also pass between worlds.

Long before their nature was understood, meteoroids no larger than a small pebble continually attracted attention. Earth's atmosphere protects us well, however, so we have nothing to fear from colliding with a pebble. But the fact that each colliding meteoroid has an enormous velocity with respect to the Earth, typically between ten and forty miles per

second, has noteworthy consequences. Unable to move out of the way as the meteoroid plunges toward Earth, atmospheric gases pile up ahead of it, just as they do at the front of the space shuttle as it re-enters our atmosphere. The pressure exerted by the swiftly accumulating head of atmospheric gas heats the meteoroid (and the shuttle) to 3,000 degrees Fahrenheit or higher. Even a pebble-size meteoroid heats enough of the surrounding gas, as well as itself, to create a bright "shooting star"—the transitory visible object astronomers call a meteor.

Although a typical shooting star may appear to land over the next hill, it actually flames out between twenty-five and eighty miles above the observer. During the meteoroid's roaring trip through the atmosphere, most of its mass sloughs off as tiny shards of matter. To survive such a violent passage, and thus to reach Earth's surface as even a small remnant meteorite, the original meteoroid must be larger than a chair. Most meteors never end up as meteorites. When they do, they can be identified soon after their fall by their still-warm surfaces. Identifying older meteorites on the ground usually takes a practiced eye and a good deal of luck. On rare occasions a fall of hundreds of meteorites spreads over a few square miles.

The Willamette Meteorite, which weighs almost sixteen tons, was discovered near Oregon City, Oregon, on November 9, 1906. It is now in the collection of the American Museum of Natural History in New York City.

On the basis of their composition, meteorites are classified into three main groups: stony, stony-iron, and iron. Each group embodies, in the details of its chemical composition, the history of its formation far from the Earth. The oldest meteorites are the stony ones, and within that group the oldest of all are the chondrites, so named for their rounded, glassy inclusions called chondrules.

Henry Clifton Sorby, a nineteenth-century meteorite enthusiast, described chondrules as "droplets of fiery rain." Dating of the chondrules, based primarily on the radioactive uranium they contain, has identified chondrites as old as 4.6 billion years, far older than any other rocks on the Earth or the Moon. This age dates the oldest chondrites to the epoch when the Sun and its planets began to form within a diffuse cloud of gas and dust. Within a few million years, many of those pieces had joined together to form the large objects that now orbit the Sun: the four inner, rocky planets; the Earth's moon; and the solid cores and large moons of the four gas-giant planets.

Some material from the primordial solar system, however, never became part of a planet or a large moon. Instead, that debris continued to orbit the Sun, most of it between the orbits of Mars and Jupiter, a region known as the asteroid belt. Asteroids are just meteoroids large enough to be identified with a telescope as individual objects; the asteroid belt comprises not only thousands of asteroids but also millions of smaller objects.

Today, more than four and a half billion years after the Sun and its planets formed, most of the leftover debris continues to orbit outside the orbit of Mars. But gravitational forces from the other planets continually divert some of the debris into smaller orbits that cross the Earth's. When our planet encounters a region particularly rich in debris, most notably in mid-August and in mid-November, everyone in the world gets the chance to see a "meteor shower." On every clear night of the year, though, dozens of meteors can be seen by anyone with decent vision (or a good pair of glasses) and the patience to gaze steadily at the sky.

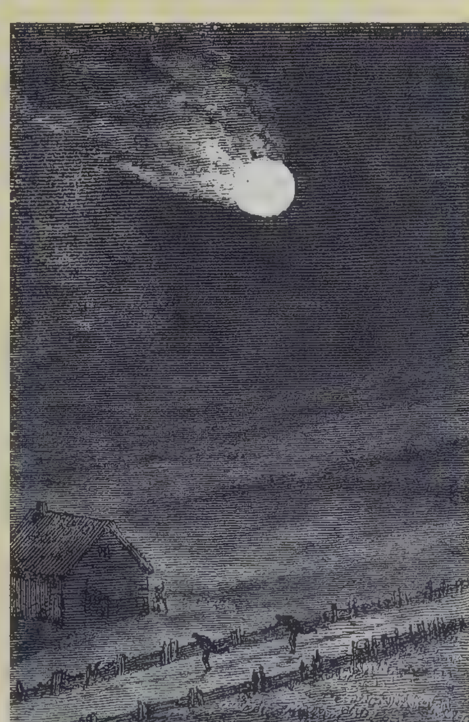
And of all the meteoroids that reach the Earth's surface, the vast majority are, in effect, minute asteroids.

But what of the meteoroids that come from other large objects in the solar system? To escape from Venus or the Earth, matter must be ejected at a velocity of at least seven miles a second; on Mars, three miles a second will suffice. No modest impact can ping matter off a surface at such speeds; the impactor must be more than 300 feet across, substantially larger than the one that excavated the Barringer crater.

Leonid meteor shower of November 12, 1799, as seen off the southeast coast of Florida

Once blasted into space, a typical fragment traces an elongated trajectory around the Sun. On every orbit, it makes a close approach to the planet it came from, and the gravity of that planet either recaptures it or deflects it into a new orbit. If the new orbit becomes so elongated that it crosses the orbit of another planet, the second planet's gravitational field may pull the fragment into its embrace. In some cases that second planet is Jupiter—by far the most massive planet, whose gravitational force can either capture the fragment or launch it entirely out of the solar system. But a sizable fraction of the material ejected from either Mars, Venus, or the Earth—more than one-third—actually ends up on the surface of one of the other two planets.

Of course, finding such interplanetary messengers depends a great deal on where they fall. Most of them, given the ratio of water to land on the Earth's surface, plunge unseen into the oceans. But on the slowly flowing ice fields of Antarctica, where other rocks are scarce, meteorites are ripe for the plucking. Of the several-score meteorites that have been securely identified as hailing from the Moon or from Mars, two dozen or so have been antarctic finds.



A dazzling bolide streaked across midwestern skies on February 12, 1875.

The chemical composition of every meteorite identified as lunar or Martian differs, subtly but surely, from the composition of every terrestrial rock. The chemical profiles of the meteorites match those of rocks sampled on Mars and on the Moon several decades ago [*see "Moonstruck," by G. Jeffrey Taylor, page 46*]. Strangely, no meteorites from Venus have yet been identified, though some of them should have reached the Earth, and a chemical analysis of the Venusian surface has been available for a quarter century. The luck of the cosmic draw may have led to that negative result; better meteorite searches may soon change it.

By examining Martian meteorites for the effects of impacts from cosmic rays—fast-moving, highly energetic atomic nuclei that permeate space—physicists have determined that they spent between 12 million and 17 million years in interplanetary transit before colliding with the Earth. All but one of those meteorites are less than 1.3 billion years old. The lone exception is a meteorite designated ALH 84001, so named because it was the first meteorite discovered in the Allan Hills of Antarctica in 1984.

In 1996, however, ALH 84001 became the most famous meteorite on the planet. An interdisciplinary team of scientists announced that this rock from Mars bore intriguing clues that life had once flourished on another planet. Moreover, the radioactive decay of minerals within the meteorite showed that the rock had formed 4.5 billion years ago, a time early in the history of the solar system. In that distant epoch the surface of Mars apparently had abundant running water, and thus a far greater potential than it does today for harboring life on its surface.

What were the signs of life within ALH 84001? First, it contained compounds that often occur in organisms on Earth. Second, it included tiny, magnetized grains of iron oxide and iron sulfide much like the ones that certain bacteria pro-

duce to orient themselves in the Earth's magnetic field (Mars, too, must once have had a substantial magnetic field). Finally, it held within it a number of submicroscopic ovoid shapes, similar in form to various tiny fossils on Earth but much smaller than any of them.

For a few months many investigators hoped ALH 84001 would demonstrate that ancient life on Mars had been brought to Earth by two cosmic collisions: one that blasted the rock loose from Mars in the first place, and a second, 15 million years later, that slammed it into our planet. Alas, the verdict has largely gone against the believers (though there are still holdouts). Some earthbound organisms may have contaminated the meteorite. The resemblance between its mineral inclusions and the magnetic grains made by bacteria is apparently just happenstance. And the ovoids, too small to hold the molecules needed to carry out the chemical reactions of life, are just chance deposits with interesting shapes.

Meteor storms are rare, but this portrayal of a spectacular storm on the night of November 12–13, 1833, is not fanciful. Witnesses in eastern North America reported sighting tens of thousands of meteors, and a succession of brilliant fireballs.

Nevertheless, ALH 84001 is a striking reminder that whenever a giant impact dislodges a life-bearing fragment from an inhabited world, life from that world could travel to another. In principle, since Jupiter's gravity expels some meandering meteoroids from the solar system, life might even be able to cross interstellar distances millions of times greater than the distance between Earth and Mars, eventually to find its way onto worlds that belong to other planetary systems.

Panspermia, the concept that all life in the universe had a common origin and has been carried from planet to planet with the passage of time, sprang from the mind of the Swedish chemist Svante Arrhenius at the beginning of the twentieth century. The demonstrated fact that material does travel from one planet to another lends credence to the hypothesis. But could any life-forms have survived the shock of the blastoff, the long, harsh cold and exposure to radiation in space, and the final trauma of passing through a planet's atmosphere and colliding with its surface?

Apparently they could have. Calculations of the blast-off process, together with experiments on such hardy bacteria as *Bacillus subtilis* and *Deinococcus radiodurans* (the latter notable for surviving doses of radiation a few thousand times the lethal dose for a human being), imply that microorganisms can survive not only the shock of impacts like the ones required to eject matter into interplanetary space, but also millions of subsequent years of orbiting in the cold. Microorganisms in space can be protected against interplanetary ultraviolet radiation by a few microns of shielding, which even a small rock can provide. (Protection against cosmic-ray particles might require several feet of solid material, implying that only relatively large ejected rocks could ferry life safely through space.) Some forms of life can remain dormant for many centuries, and possibly even for the thousands of millennia it takes for a meteoroid to travel from planet to planet.

Passing through a planet's atmosphere, even one as thin as the veil surrounding Mars, substantially slows down a meteoroid before it lands. During that ten- or twenty-second passage, as its surface becomes red-hot, much of the meteoroid breaks apart or flakes off. But the passage happens so quickly that the interior of any sizable meteoroid fragment, including any microorganisms along for the ride, could remain cool. H. Jay Melosh of the University of Arizona in Tucson, the leading expert on the exchange of matter between planets, puts it this way: "Earth's atmosphere—and Mars's to some extent—couldn't have been better designed to let organisms down gently."

How can one estimate the probability that life-forms do travel from world to world, as Arrhenius envisioned? One conclusion seems rock-solid: The distances between the planets within our solar system (or within other planetary systems) make such a transfer billions of times more likely *within* a single planetary system than *between* planetary systems. Thirty years ago Carl Sagan concluded that probably not a single meteorite from another planetary system could ever reach the surface of the Earth. Earlier this year Melosh undertook detailed calculations to demonstrate systematically that Sagan's assertion remains valid. The vast distances between the stars make the interstellar-panspermia hypothesis—that life has been transferred not only within a planetary system but also between systems—mathematically almost impossible, no matter how well a life-form could survive an interstellar voyage.

But for travel between the planets within a particular system, panspermia seems entirely possible. The Martian meteorites demonstrate that much already. Life on Earth may yet prove to be descended

A bright shooting star blazes a trail of hot gases as it burns up in the topmost reaches of the atmosphere, between twenty-five and eighty miles above the ground. If you're in the right place at the right time, you may witness such an event any clear night of the year. The U.S. astronomer Edwin Emerson Barnard captured this meteor in a wide-field photograph in December 1916.

from ancient life on Mars—and any ancient life on Mars may in turn have come from Earth.

Even if meteorites turn out not to have brought life to Earth from other planets (or vice versa), they still arrive here loaded with useful information. Geologists have noted, for instance, that every meteorite from Mars contains carbon-oxygen compounds, sulfur-oxygen compounds, and minerals common in terrestrial clay—all of which signal that water was present at the time they were formed.

Perhaps even more amazing is what geologists have deduced about the geologic history of Mars from what might seem meager evidence in eight Martian meteorites. The key to the deduction lies in what can be inferred from the measured ratios of various isotopes in various rocks. (A chemical element can occur in nature in several varieties called isotopes. The isotopes of any one element are identical in their chemical properties, but they differ in mass as well as in stability against radioactive decay.)

Geologists Der-Chuen Lee of the Academia Sinica in Taiwan and Alexander N. Halliday of the Swiss Federal Institute of Technology in Zurich measured the proportions of various isotopes of tungsten in the eight meteorites from Mars. Tungsten-182, a rare isotope, arises from the radioactive decay of hafnium-182. The measured quantity of tungsten-182 in a meteorite therefore shows how much hafnium-182 was present in the rock when it formed. From that measurement, it was straightforward to calculate how much hafnium of all isotopes was present in the original rock.

Lee and Halliday then measured the total amount of tungsten in the meteorites, almost all of which is tungsten-184. All tungsten combines readily with iron-rich material, which, because of its high density, tends to concentrate in the core of a planet. Hence tungsten, too, became concentrated in the core. As a consequence, the rocks that did not contain much iron became relatively depleted in tungsten. Those rocks were the ones that came to form the Martian crust and mantle.

In contrast with tungsten, hafnium does not interact readily with iron-rich material, but it does combine readily with the elements in rocks lacking in iron. Hence when a planet differentiates into an iron-rich core and an iron-poor crust and mantle, hafnium tends to end up in rocks outside the core. The ratio of tungsten-182 (which came from hafnium) to total tungsten in the Martian meteorites turned out to be relatively high, signaling that the region from which they originated had been part of the early crust.

Furthermore, Lee and Halliday concluded, Mars must have differentiated itself into core, mantle, and crust within a few tens of millions of years after it formed. Thereafter it has remained geologically quiet, its crust relatively intact for almost the entire history of the planet. If, during the past four billion years, Mars had instead undergone plate-tectonic activity similar to that on Earth, more material from the core would have found its way into the crust. In that case, the ratio of tungsten-182 to tungsten-184 would have been lower, because much more tungsten-184 from the original core would have been mixed into the crust.

Even if meteorites turn out not to have ferried life to Earth, they still arrive here loaded with information.

This December the European Space Agency's Mars Express lander *Beagle 2* is scheduled to touch down on the Martian surface. The following month NASA's Mars Exploration Rover Mission will put two robot rovers on opposite sides of the red planet to scrutinize the surface for signs of water and provocative rocks. Someday within the next decade or two, Martian materials may be brought to Earth for analysis. A detailed examination of them should yield geologic conclusions even more startling and fine-grained than the ones derived from the tungsten isotopes. For example, if sedimentary rocks exist on Mars, they may contain fossil evidence of life from the era when liquid water flowed on the planet's surface.

Someday, too, well before this century ends, geologists will walk on Mars; one of their number has already walked on the Moon. Their explorations will enhance the findings of the robot investigators that preceded them. Perhaps they will find rocks containing evidence of life—or possibly life itself—hidden beneath the Martian surface. Until then, we earthlings can continue to look for microscopic visitors, or their fossil remnants, that might reside in meteorites from Mars or from other worlds. The full implications of those interplanetary transfers, which depend on a more complete knowledge of what those visitors from other worlds have carried to Earth, will be intriguing to sort out. □

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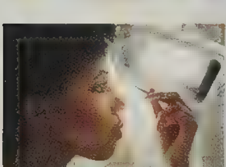

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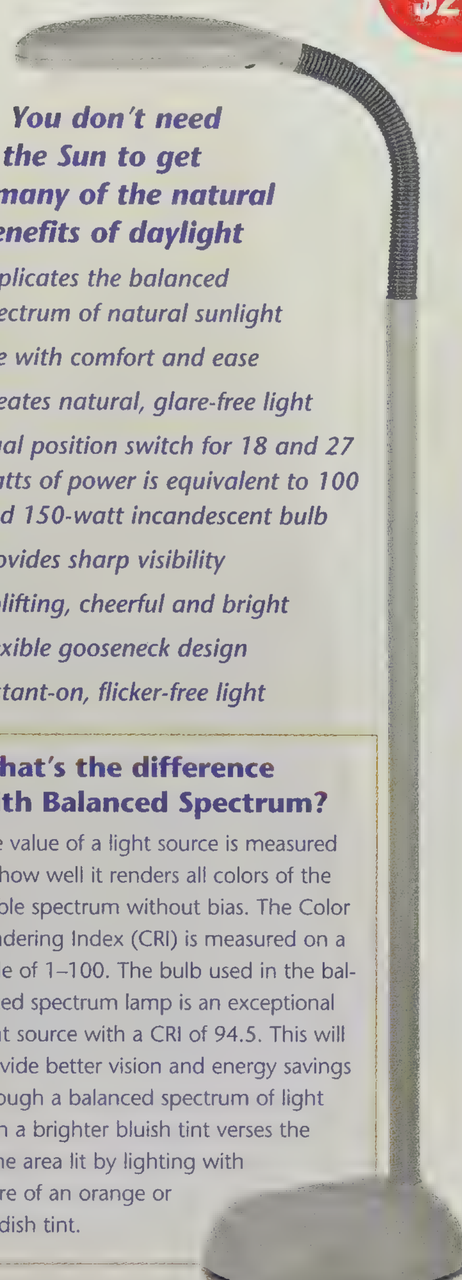

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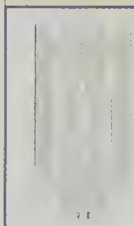

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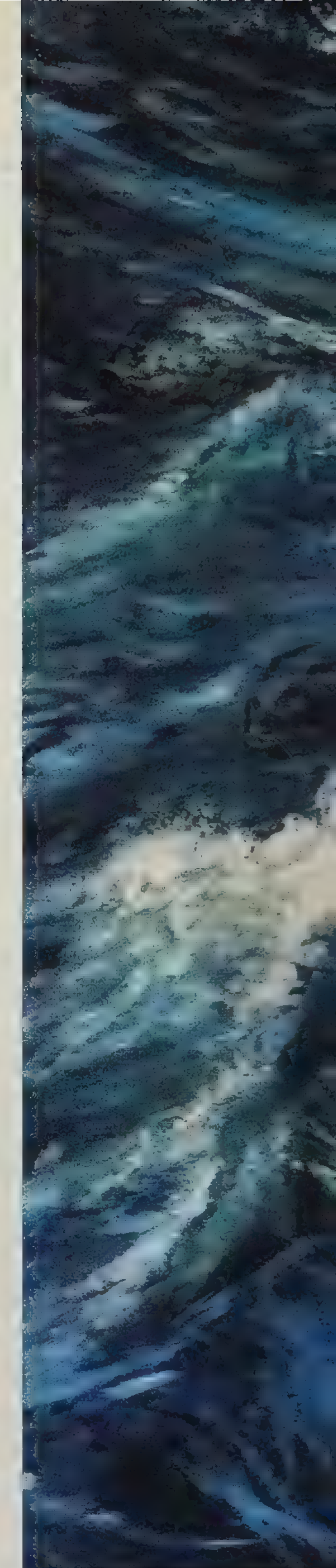
Terrible Lizards of the Sea

When dinosaurs ruled the land, other giant reptiles stalked the deep. Some may have borne more than a passing resemblance to sea serpents.

By Richard Ellis



In 1780 in Maastricht, Netherlands, workers in a limestone mine ninety feet deep discovered the huge jaws and part of the skull of an unknown fossil creature. An army surgeon named C. K. Hoffmann directed the quarrymen to bring the entire rock containing the find to the surface, but soon lost possession of it. The prize was claimed by the landowner, a clergyman named Goddin, who in turn had to watch helplessly as it was carried off by Napoleon's army in 1795. It is now on view at the National Museum of Natural History in Paris.

What was this rockbound monster? Pieter Camper, a renowned Dutch anatomist of the day, believed the jaw, which measured more than five feet long, belonged to a toothed whale. One of Camper's contemporaries, the French naturalist Barthélemy Faujas de Saint-Fond, likened it to a crocodile. Unswayed by the creature's size, Camper's son Adriaan Gilles Camper correctly pointed out its resemblance to lizards of the family Varanidae, such as the monitor lizard. In 1822 the animal was accorded a genus name, when the English geologist and clergyman William Daniel Conybeare called it *Mosasaurus,* from *Mosa,* the Latin name of the Maas (Meuse) River near Maastricht, and *saurus,* for "lizard." Later, the hapless surgeon Hoffmann was honored in the species name, *hoffmanni.*

That first specimen gave its name, in more general form, to all its relatives that followed it into the limelight of paleontology. A diverse group of aquatic reptiles, the mosasaurs arose about 90 million years ago, in the middle of the Cretaceous Period, and flourished for 25 million years. All were lizards, and thus only distantly related to their terrestrial counterparts, the dinosaurs [*see illustration at the top of page 39*]. Although almost certainly descended from terrestrial forebears, mosasaurs adapted well to the open seas, and some species reached enormous size. In the ocean they achieved a commanding position as predators that would not be matched until whales and dolphins appeared on the scene 30 million years later.

The proliferation of the mosasaurs followed a dramatic rise in worldwide sea levels, when shallow seas covered much of Europe and North America. Sea levels eventually fell once again, rendering the remains of the mosasaurs accessible, and the discovery of gigantic sea lizards in the badlands of the American West captured the public's imagination in a way exceeded only by the unearthing of the dinosaurs themselves. In a chapter titled "Wonder of the Kansas Plains," in his 1887 book *Sea and Land: An Illustrated History of the Wonderful and Curious Things of Nature Existing before and since the Deluge,* James W. Buel expressed the public's amazement:

The fabulous monsters that were believed in in the

Mosasaurs, a diverse group of aquatic reptiles, arose about 90 million years ago and coexisted with the terrestrial dinosaurs until both groups were wiped out when the Earth collided with an asteroid, 65 million years ago. Tylosaurus proriger, the mosasaur envisioned in this 1899 painting by Charles R. Knight, preyed on fish, shellfish, and probably certain large aquatic birds, as well as on other small mosasaurs and plesiosaurs. The species could grow as long as fifty feet and weigh as much as eleven tons.

olden times, the dragons, serpents, etc., are thrown in the shade by these truly ancient monsters that once swam in the ocean that finally became land-locked, and the bottom of which is now raised high above the water level. The shore line of that old ocean is distinctly marked. Imagine the water between New York and London a dry plain, its whales and fishes stranded in the mud, on the sides of the great hills, and on the plateaus that we know exist, and an idea can be formed of the *mauvaise terres.* [Yale paleontologist O. C.] Marsh says that in one place he counted from his horse the remains of five huge monsters spread upon the plain.

Coincidentally, *M. hoffmanni,* the first mosasaur species to be recognized, still holds the record for size: Theagarten Lingham-Soliar, a paleontologist at the University of Durban-Westville in Kwazulu-Natal, South Africa, estimates that in life the Maastricht specimen was fifty-eight feet long and weighed between twenty and twenty-two tons. He thinks the creature may have lived in nearshore waters that were perhaps between 130 and 165 feet deep. Other species took to the open ocean, and may have dived deeply for prey. Still others lurked

in the shallows, ready to ambush anything that happened by, or developed heavy, rounded teeth that enabled them to crush the thick shells of bivalves. All of them vanished, however, around the same time the last of the terrestrial dinosaurs and airborne pterosaurs met their doom.

Or did they? According to one theory, the snakes—a group whose origins remain shrouded in mystery—share such a close kinship with the extinct mosasaurs that they almost could be considered the surviving branch of the lineage.

The immediate ancestors of mosasaurs have not been identified, but they probably looked a lot like aigialosaurs, usually considered shore-living, semiaquatic lizards. Aigialosaurs were three or more feet long, with a tail as long as the head and body combined, not unlike today's monitor lizards. Anatomically, they could well pass for mosasaur ancestors. But no fossils of them have been found that are older than those of the mosasaurs themselves, so it is safer to regard them as a sister group. Once mosasaurs began to evolve in the sea, however, they quickly traded their feet for flippers, and their tails lengthened and became vertically flattened, like those of eels and crocodiles. Whereas their ancestors had laid eggs on land, mosasaurs developed the ability to deliver young alive in the water.

Fossilized jaws and partial skull of Mosasaurus hoffmanni *are removed from the limestone mine in the Netherlands where they were discovered in 1780. The fossil was the first, and remains the largest, mosasaur ever found.*

Mosasaurs may have been ectothermic, or cold-blooded, as are all living reptiles; the shallow seas and coastal waters where many species lived would have been relatively warm. But some species appear to have dived deeply or frequented cooler depths, so perhaps they were partly endothermic, or warm-blooded. In any case, mosasaurs were active predators. The lower jaws, which were only loosely connected at the front, each had a hinge joint in the middle, enabling the animals to swallow large prey. A system of continual tooth replacement ensured an ever-sharp battery of teeth. In addition, in most species the pterygoid bones that made up the hard palate on the roof of the mouth were equipped with teeth that kept slippery fish, squid, or other prey from wriggling free after they had been grabbed by the jaw teeth.

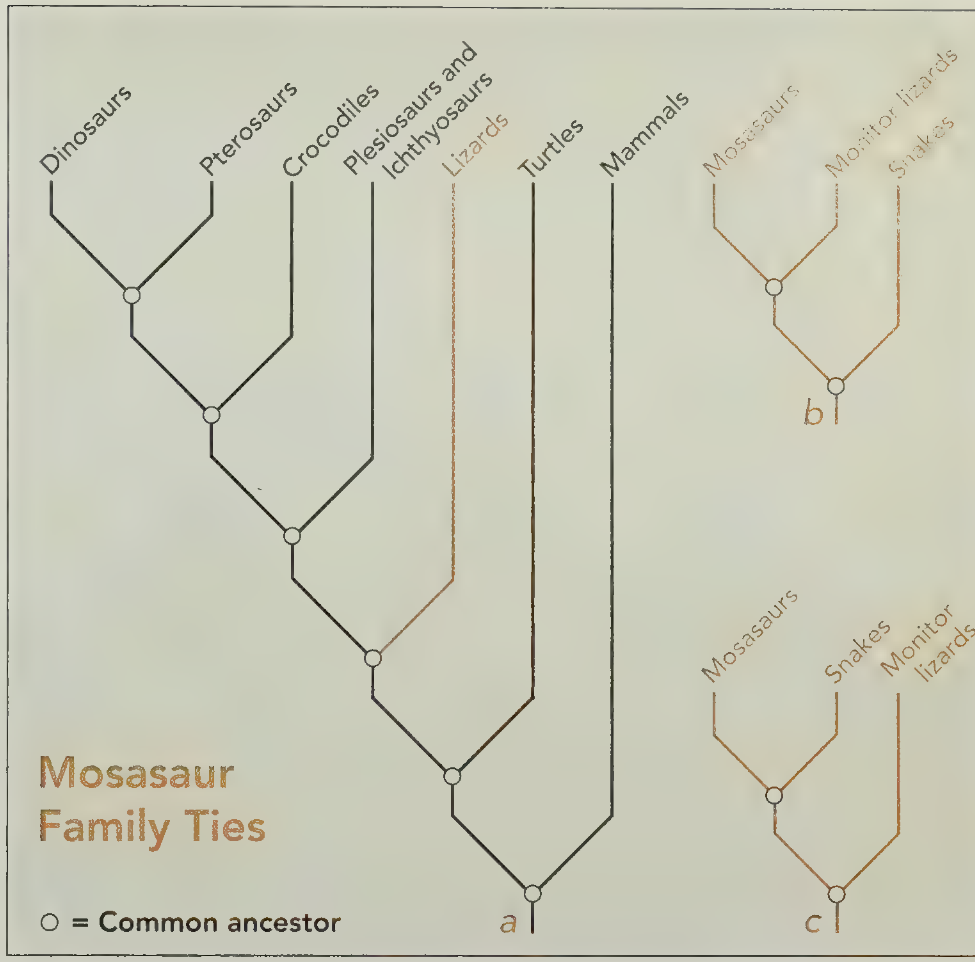
Mosasaurs were not the only reptilian predators in the seas; others were well established by the time they appeared, notably the plesiosaurs (with four flippers and, often, elongated necks), the crocodilians, some gigantic sea turtles, and the ichthyosaurs (which were shaped somewhat like dolphins but had a sharklike, vertical tail fin). By the time of the mosasaurs, however, the ichthyosaurs were heading toward extinction, though they had been around for nearly 150 million years. As a group they had started out as ambush predators, but they had evolved into species that caught their prey by pursuit. Unfortunately for the ichthyosaurs, fish were getting harder to catch. As Lingham-Soliar has observed, the fast, highly evasive bony fishes were thriving at the time and spreading around the globe, and so the energy costs of catching prey by pursuit were becoming increasingly untenable for marine reptiles.

Mosasaurs excelled instead as ambush predators. Judy A. Massare, a paleontologist at the State University of New York College at Brockport, has analyzed their swimming capabilities, and she concludes that mosasaurs could accelerate rapidly to capture prey. The long, thin shape of the animal, she notes, enabled it to cut through the water with minimal resistance while using its large body surface for propulsion. Moreover, she explains, the end of the creature's long tail would have generated extra thrust, particularly in species that had an expanded end to the tail.

In many of the earliest descriptions of swimming mosasaurs, scholars speculated that the reptiles undulated their entire bodies, like snakes or eels. In 1991, however, Lingham-Soliar concluded from a study of mosasaur vertebrae that only the rear two-thirds of the animal's body undulated when it swam; the forward third was stiffened. The motion, he said, was similar to that of a swimming

cod, an American alligator, or a Galápagos marine iguana. Then, just a year later, Lingham-Soliar proposed that one large mosasaur, *Plioplatecarpus marshi,* essentially "flew" underwater, like a penguin or a California sea lion, using its flippers in up-and-down movements instead of a forward-and-back rowing motion.

The idea of underwater flight in mosasaurs has sparked spirited debate among paleontologists. Elizabeth L. Nicholls of the University of Calgary in Alberta, Canada, and Stephen J. Godfrey of the Calvert Marine Museum in Solomons, Maryland, note that in penguins and similar underwater fliers, the tail is much smaller than it is in nonfliers. But, they maintain, there is no reason to think that the tail was unusually short in this species. They also contend that the animal's huge flippers would not have been particularly effective as "wings," and that the species' powerful pectoral girdle—the skeletal arch that supported its forward fins—could have served other functions. Certain sharks, for instance, shake their prey violently to dismember it into edible chunks, and they have similarly well-developed pectoral girdles that support the "sharp movements of [their] pectoral fins."



Genealogical family tree of reptiles and mammals (a) shows that lizards—including mosasaurs—are no more closely related to dinosaurs than they are to several other major reptile groups. Within the lizard group, both mosasaurs and snakes are considered closely related to lizards of the family Varanidae, whose living representatives include the monitor lizards. A common view (b) is that snakes and mosasaurs are fairly distant relatives, but according to a more recent suggestion (c), snakes and mosasaurs share a close common ancestor.

One of the most formidable of the mosasaurs was *Tylosaurus proriger,* a species that could grow as long as fifty feet and weigh as much as eleven tons. It had a slim body, huge jaws, and heavy, sharp, cone-like teeth. Its trademark feature, though, was the elongated tip of its muzzle, which projected eight inches beyond the frontmost teeth in the upper jaw. The protuberance may have acted as a ram that could stun prey, defend against sharks and other predators, or battle rivals of its own species.

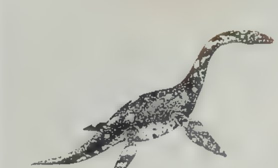
Tylosaurus inhabited the shallow Niobrara Sea, which once covered what is now the Great Plains of North America. The animal preyed on fish, shellfish, and probably certain large aquatic birds, as well as on small mosasaurs and plesiosaurs. That description of its diet is not just guesswork. In 1987 James E. Martin and Philip R. Bjork, both of the Museum of Geology at the South Dakota School of Mines and Technology in Rapid City, described the stomach contents of a South Dakota fossil of *Tylosaurus.* The stomach included the remnants of the diving bird *Hesperornis,* a bony fish, a shark, and a small mosasaur.

Not all mosasaurs ambushed or chased down fast-moving prey. The genus *Globidens* had rounded teeth instead of the more typical conical spikes. Those teeth were adapted not for gripping prey, but for crushing shellfish, probably ammonites. Such round-toothed species were also the only mosasaurs that did not have palatal teeth: crushed shellfish did not have to be "walked" to the throat the way struggling vertebrates did.

Specimens of mosasaurs that have been excavated are about ten times as plentiful as dinosaur fossils are. Yet despite the large body of evidence, some questions about them have been difficult to answer. For a long time, for instance, no one knew how they were born. Mosasaurs seem ill equipped to have laid eggs on land, as sea turtles do. But if they gave birth to live young, one would ex-

Extinct Marine Reptiles

Ichthyosaur



Plesiosaur

Mosasaur

pect to find embryonic bones preserved with some of the adult skeletons.

It was not until the 1990s that Gorden L. Bell of the Museum of Geology at the South Dakota School of Mines and Technology discovered the bones of two prenatal mosasaur embryos, along with the fragmentary remains of the mosasaur *Plioplatecarpus primaevus.* The bones were disarticulated, but that seemed to have been caused by scavenging dogfish sharks, whose teeth were abundantly preserved in the immediate vicinity. Further support for a live-birth life cycle came in 2001, when Michael W. Caldwell of the University of Alberta in Edmonton, Canada, and Michael S. Y. Lee of the University of Adelaide in Australia published a description of a fossilized aigialosaur with at least four well-developed embryos. The orientation of the embryos suggested birth was tail first, which would have reduced the possibility of drowning.

Another matter of contention has been whether any mosasaurs were deep divers. Bruce M. Rothschild and Larry D. Martin, both from the University of Kansas Natural History Museum in Lawrence, examined the fossilized vertebrae of some North American mosasaurs for evidence of a bone disease called avascular necrosis. The disease was present in nearly every skeleton they examined of *Tylosaurus* and *Platecarpus,* two of the most common mosasaur genera. Avascular necrosis occurs when the blood supply to the bones is cut off. It is the telltale sign of an episode of decompression sickness, commonly known as "the bends," which is caused by the formation of nitrogen bubbles in the bloodstream as an animal ascends after a deep dive.

Rothschild and Martin conclude that the mosasaurs belonging to those two genera were deep-water specialists that may have dived too often and gone too deep. The episodes of the bends, the investigators speculate, may have resulted from crises such as the need to escape predators, or the reckless pursuit of prey. They also report that in South Dakota, skeletons of large mosasaurs occur in the same area as the remains of giant extinct squids. "It is possible," they write, "that *Tylosaurus* may have dived to great depths to capture squid, as the modern sperm whale does now."

For some paleontologists, however, the jury is still out on deep diving. Amy Sheldon of Oklahoma Panhandle State University in Goodwell, for instance, disagrees about the deep-diving ability of *Platecarpus.* The animal had relatively dense, heavy bones, she notes, which would have tended to keep it submerged. Present-day sea cows, she continues, have dense bones, and they inhabit only shallow waters. In contrast, dolphins, some whales, ichthyosaurs, and some turtles have porous, light bones, and many dive (or dove) deeply.

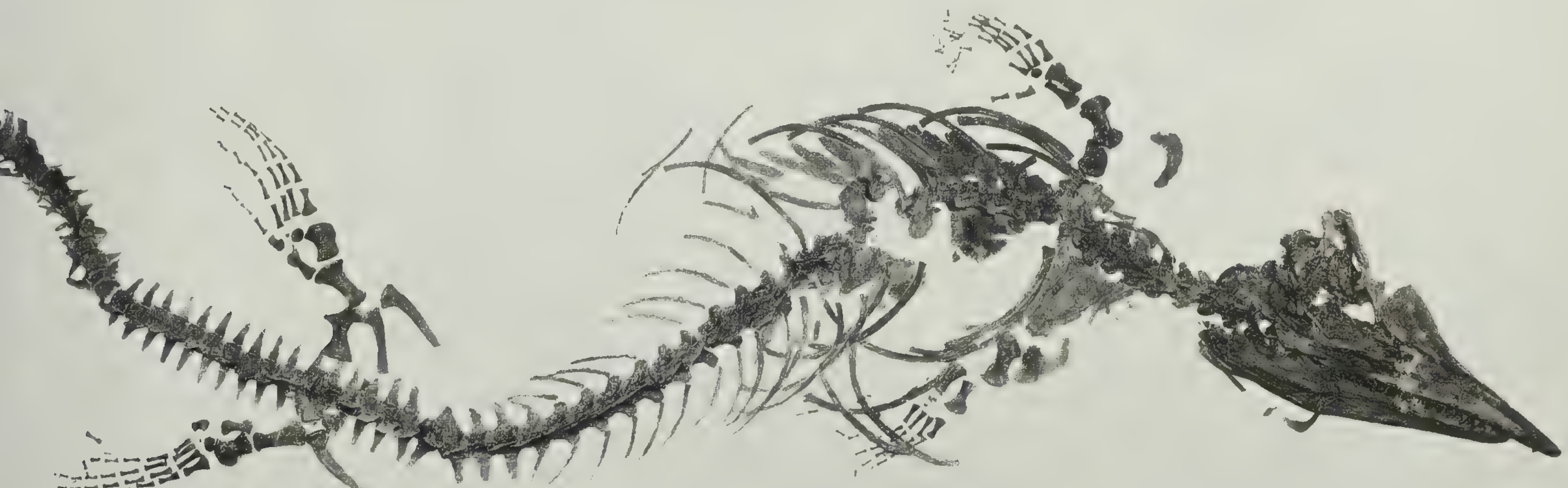
Pachyophis woodwardi, dating from about 95 million years ago, is one of the earliest known snakes. To some investigators its relatively heavy ribs suggest it was a marine species, and perhaps a close relative of the mosasaurs.

Perhaps the greatest mystery about the mosasaurs is their disappearance. For at least 25 million years they prospered, spreading throughout the major oceans of the world. It seems unlikely that they had reached anything like their evolutionary potential at the time they vanished. Yet vanish they did, 65 million years ago.

Few would doubt that their demise was linked to the same asteroid impact and disruption of the food chain that wiped out the pterosaurs and the terrestrial dinosaurs. The plesiosaurs also disappeared at the same time (unless one insists on the existence of the fabled Loch Ness monster). Of the large marine reptiles, only crocodiles and sea turtles somehow survived.

But did all mosasaurs really disappear? In recent years many paleontologists have embraced the view that birds are descended from one group of dinosaurs, and so birds must be considered dinosaurs, too. If so, the familiar claim that dinosaurs became extinct is no longer tenable. No one yet is demanding quite such a radical shift in paleontological thinking about mosasaurs. But Caldwell,

Lee, and others are now ruffling some paleontological feathers, so to speak, by maintaining that snakes and mosasaurs are more closely related to each other than either group is to any other group of lizards. In support of that view, they point out, for instance, that snakes, like mosasaurs, possess palatal teeth as well as flexible lower jaws that enable them to swallow large prey.



Fossilized skeleton of a thirty-foot-long Tylosaurus proriger *shows that the animal was a formidable predator. The flattened tail provided strong propulsion for ambushing prey. The projecting tip of its skull, a trademark feature of this and similar species of mosasaurs, may have acted as a ram for stunning prey, defending against sharks, or battling rivals.*

It has generally been thought that the first snakes were terrestrial, and that their ancestors were terrestrial lizards similar to the ones belonging to the family Varanidae—the same family that is regarded as close to the mosasaurs. But in the newly proposed scenario, the mosasaurs, together with the earliest snakes and certain lizards such as the aigialosaurs—all of them aquatic—evolved from a common aquatic or semiaquatic ancestor [*see illustration at top of page 39*]. The earliest terrestrial snakes then descended from their aquatic forebears, and, as herpetologists have long maintained, the aquatic snakes that exist today descended even later from the terrestrial snakes.

Where, however, is the fossil evidence that marine snakes preceded terrestrial ones? Terrestrial snakes were indisputably present about 100 million years ago, and perhaps somewhat earlier. That date sets the bar for finding early marine snakes. One early candidate, *Pachyophis woodwardi,* dating from about 95 million years ago, was originally described as a snake in 1923 [*see photograph on opposite page*]. Lee and his colleagues have reevaluated that fossil; its relatively heavy ribs suggest to them that the species was marine, but the evidence is equivocal. Another fossil snake of about the same antiquity, *Pachyrhachis problematicus,* was described by Caldwell and Lee in 1997. Discovered in a limestone quarry some twelve miles north of Jerusalem, it is nearly four feet long. It had small hind legs—including femur, tibia, fibula, and tarsals—as well as other characteristics that, they argued, support the idea that snakes are closely related to mosasaurs.

The same limestone quarry from which *P. problematicus* was excavated has yielded another 95-million-year-old fossil snake species, *Haasiophis terrasanctus.* But as often happens in paleontology, a newly unearthed fossil can confuse more than it clarifies. Analysis of the specimen by the late paleontologist Eitan Tchernov and his colleagues led to another interpretation. *H. terrasanctus* was about three feet long and also had legs, but its jaw structure appears more closely related to the larger, living snakes of today than the jaw of *P. problematicus* does. Hence it could be, as Tchernov and his coworkers suggested, that both *P. problematicus* and *H. terrasanctus* were advanced snakes that had re-evolved legs from vestigial structures.

The descent of snakes is a contentious topic in vertebrate biology and is not likely to be settled without more hard evidence. Unfortunately, the bones of small snakes are delicate and their fossils are hard to come by. Nevertheless, Caldwell and Lee have stimulated some new thinking. In their 1998 book *The Evolution Revolution,* Kenneth J. McNamara and John Long, both of the Western Australian Museum in Perth, welcomed the mosasaur connection, giving it a down-under perspective:

> When you are next out snorkeling and are startled by a sea snake, it may not only be some highly derived snake that you are frantically paddling away from, but all that remains of a great radiation of aquatic reptiles that once dominated the seas. □

This article was adapted from Richard Ellis's forthcoming book, Sea Dragons: Predators of the Prehistoric Oceans, *which is being published by the University Press of Kansas in October.*

*The dragon's blood tree (*Dracaena cinnabari*; seen close up, above, and in its habitat at right) grows by sending out branches that bifurcate in a predictable, simple, self-similar manner. According to Friedrich E. Beyhl, a botanist in Kelkheim, Germany, the branching can be modeled as a fractal, a mathematical object that branches repeatedly according to a simple rule.*

Of more interest to the people of Socotra (and beyond) is the tree's resin. Pliny, the Roman natural historian, called it cinnabaris *for its red color, and reported that the red liquid was pressed from a dragon's body by a dying elephant. Gladiators would smear the resin on their bodies before combat, both for its ferocious, intimidating red color and for its disinfectant properties in treating wounds. Dragon's blood appears in the Nordic saga of Sigurd in the same role. The Arabic word for the resin is* dam al-akhawein, *"the blood of the two brethren," which alludes to the legendary twins Castor and Pollux. (The Greek name for the islands, Dioscorida, alludes to those twins, too.) It was a common ingredient in varnishes of the past; Socotrans today decorate pottery with the dark resin.*

One of the closest relatives to D. cinnabari *today grows on the Canary Islands in the Atlantic; evidence from fossil pollen suggests that some 20 million years ago the tree and its relatives spanned the length of the arid southern shore of the Tethys Sea, the remnant of which we know today as the Mediterranean.*

Splendid Isolation

With several hundred endemic plant species, the lonely Socotra archipelago is a refuge to the old and a birthplace for the new.

Photographs by Diccon Alexander

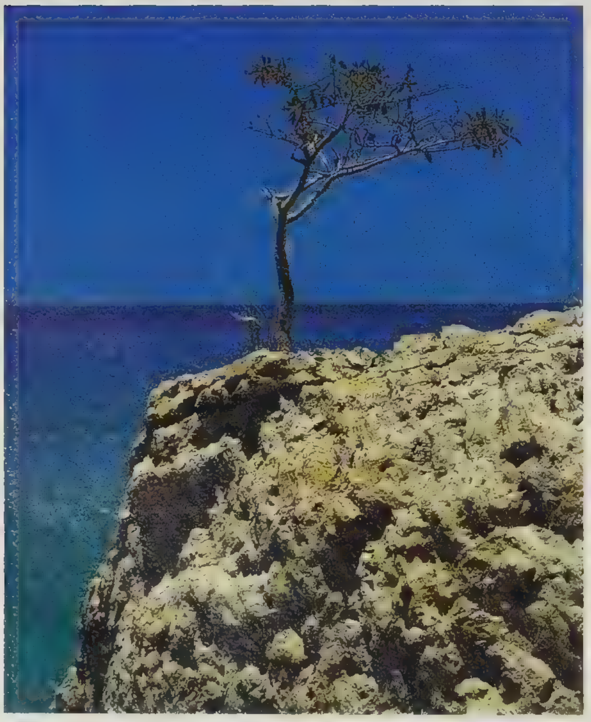
In the Indian Ocean, south of Yemen and east of the Horn of Africa, lies the Socotra archipelago—an ark of endemism comparable to the Galápagos Islands in the Pacific, or to Lake Malawi on the mainland of Africa. But it is the flora, not the fauna, of these islands that strikes the mind and dazzles the eye—no finches are here, to set the biologist's mind to wondering.

Roughly a third of the 900 plant species on the archipelago's islands live nowhere else. The dry climate has turned members of familiar groups, such as the cucumbers, into desert-adapted oddities no one would recognize in a vegetable garden. The islands, which became isolated from the African-Arabian plate some ten million years ago, give refuge to an array of living fossils as well as to so-called disjunct taxa: species whose closest relatives occur thousands of miles away.

This unique ecosystem seemed threatened by modern development as the twentieth century drew to a close. Although the islands have long been inhabited (some 50,000 people live on them today) and have long been known to the outside world (2,000 years ago a Greek or Roman sailor would have called the main island Dioscorida, considering it part of frankincense country), the United Nations and the government of a reunified Yemen (which controls most of the archipelago) became concerned that the inevitable encroachment of industrialized society would destroy Socotra's unique flora. The first step in preservation was to identify and study the species, so an international team of botanists and other biologists headed to the islands: the first time such research had been initiated in a hundred years. One of the investigators, Diccon Alexander of the Royal Botanic Garden in Edinburgh, Scotland, captured some of the plants on film. A sampling of his photographs is shown on these four pages. —The Editors

In 1887, when Western naturalists first described Dendrosicyos socotrana, the cucumber tree, it grew in Djibouti (then known as French Somaliland) as well as on the islands of the Socotra archipelago. Today the tree, which stores water in its succulent trunk, occurs only on Socotra's dry, limestone plateaus and plains. The cucumber tree is the only arborescent member of the family Cucurbitaceae (the gourds), which also includes lianas and other vines.

The cucumber tree is an extreme example of island gigantism; until 10 million years ago, when the Socotra islands were still part of the African mainland, no broad-trunked trees could have flourished side by side with such large herbivores as elephants and rhinoceroses. When the islands broke away from continental Africa, the absence of such herbivores left a new ecological niche into which the trees could grow . . . and grow.



According to the Periplus of the Erythraean Sea, a travelogue written roughly 2,000 years ago by an unknown Greek mariner, Socotra came under the domain of the king of the frankincense country. It was an appropriate addition: the species pictured here, Boswellia elongata, is one of seven frankincense species endemic to the island. Precisely what led to such a diversity of Boswellia is not known.

Euphorbia abdelkuri occupies, along with some other members of its genus, a niche similar to the cacti of the Americas; it has a succulent stem in which to store water. These cactus-like plants grow in the region known as Macaronesia (principally, the Azores, Madeira, the Canary Islands, and the Cape Verde Islands) as well as in southern and eastern Africa and on the islands of the Socotra archipelago. E. abdelkuri grows on the chain's island of Abd al-Kuri. Unlike many of its relatives, it lacks defensive spines and protects itself instead with a sap that irritates the eyes and skin, no doubt to discourage herbivores seeking a succulent feast on such a desert island.

Taxonomists place Dirachma socotrana in a family, Dirachmaceae, with only one other species (the latter occurs in Somalia). The plant is no herb; the flowers seen here are precursors of the ones that will adorn a sweet-smelling tree. On the basis of molecular data and seed morphology, Dirachmaceae belongs to the order Rosales (best known for the roses).

The Socotran desert rose (Adenium obesum sokotranum), a barrel-shaped succulent, belongs to a species that occurs throughout southern Arabia; probably little more than geographical isolation separates these plants from the main species, A. obesum. Socotran fishermen use its poisonous bark to kill small fish for bait, and pastoralists tie strips of the bark around the necks of their grazing livestock to keep wild cats—the island's only significant carnivores—at bay.

Moonstruck

Giant impacts, cataclysmic bombardments, oceans of magma hundreds of miles deep: no wonder the lunar landscape inspires such fascination.

By G. Jeffrey Taylor

The lunar surface is gray, powdery, and lifeless. There, no grassy meadows or forests grow; there, no microorganisms abide to break down the nonexistent traces of any former life. No brooks babble or rivers rage, no lakes or oceans are swayed by the Earth's tidal pull. There is no atmosphere (and so no wind). No volcanoes erupt; no tectonic plates move. So little happens on the Moon that the Apollo astronauts' footprints will last for millions of years. Only a constant rain of meteoroids slowly reshapes the surface.

The lunar landscape might sound boring, but its lack of geologic action makes the Moon an exciting place to those of us who want to understand the early history of the solar system. The Moon's cratered surface records an ancient chapter in the evolution of our own planet, one largely erased on Earth. We share a history of bombardment by ancient meteoroids, but information preserved on the Moon about the size, frequency, and duration of that early bombardment is long lost on Earth. When we lunar scientists analyze moon rocks from the Apollo collection, returned to Earth by the astronauts, or when we map the distribution of minerals and elements on the Moon, we become time travelers. We can still find on the Moon remnants of the process that separated a once-molten orb into crust, mantle, and metallic core. From the evidence found on the Moon, geophysicists can extrapolate a picture of the early history of the four terrestrial planets.

Yet when President John F. Kennedy proclaimed in 1961 that Americans would reach the Moon by the end of the 1960s, he was far more interested in outdoing the Soviet Union than he was in science. But the Cold War game of "gotcha" did yield groundbreaking scientific dividends. The wondrous Apollo missions returned to Earth with nearly 840 pounds of rock and dirt between July 1969 and December 1972. Those samples were supplemented with a few ounces of soil brought to Earth between 1970 and 1976 by the Soviet Union's Luna missions. Because the provenance of each rock and each bag of soil was carefully documented, the lunar samples have provided the "ground truth" against which to measure and calibrate the data gathered through remote sensing.

Perhaps the greatest irony of going all the way to the Moon to collect samples of its rock is that, after the fact, it became obvious that lunar rock was present here on Earth all along. It had come in the form of meteorites, blasted off the Moon by the shattering force of other, incoming meteoroids and preserved in the ice fields of Antarctica or on the hot deserts of northern Africa. The chemical compositions of those rocks, the relative abundances of the oxygen isotopes locked up in their molecules, their mineralogy, and their textures all betrayed their lunar heritage. About twenty-five separate lunar meteorite falls have been identified. Although no one knows exactly where they came from on the Moon, the lunar meteorites have provided valuable data about the composition of the lunar crust.

In 1976, after the Apollo and Luna programs had ended, attention shifted away from the Moon, and spacecraft were sent to places in the solar system where no robot had gone before. Lunar exploration remained on hold until 1990. In that year the *Galileo* spacecraft zipped past the Earth and the Moon on its way to Jupiter. Along the way, it collected lunar data. Four years later the *Clementine* spacecraft orbited the Moon, and NASA's Lunar Prospector mission followed in 1998. Those three missions carried a battery of re-

The blue planet rises over the lunar highlands, the remnants of the Moon's original crust. Anorthosite, a rock made up primarily of the mineral plagioclase feldspar, is the main constituent of the highlands. Fairly light in weight, anorthosite, precipitating from the slowly cooling ocean of magma that covered the early Moon to depths of hundreds of miles, floated to the top. The anorthosite rock then cooled to form a solid crust above the hot, liquid mantle. The crusts of the solar system's inner, rocky planets, including Earth, may have formed in a similar way. The photograph was made by the astronaut Alfred Worden during the Apollo 15 mission in the summer of 1971.

The far side of the Moon preserves largely intact a stark record of an intense bombardment of meteoroids that rained down on all the rocky planets of the inner solar system more than 3.8 billion years ago. Crater King, in the center of the photograph, is identifiable by its lobster-claw-shape central peak, which was also a by-product of the collision that created the hole. The photograph, which shows a 200-mile-wide swath of the terrain, was made by the astronauts John W. Young and Charles M. Duke Jr. during the Apollo 16 mission in April 1972, as their lunar module returned to space from its landing site on the Moon.

mote-sensing instruments that made it possible to map the chemical composition, magnetic field, mineralogy, and topography of the Moon—in short, to portray the Moon in an entirely new and far more detailed perspective.

The first astronomer to observe the Moon through a telescope was Galileo, and it was he who divided the lunar surface into two major terrains. These are generally referred to as the terrae, or "continents," and the maria, or "seas." The terrae, usually called highlands, are more heavily cratered, lighter in color, and higher than the maria; the heavier cratering of the highlands also implies that they are older than the maria. Although the maria are not seas, and the terrae are not continents, as they are known on Earth, Galileo's initial classification served lunar scientists well for a long time. He asserted that the highlands and maria are made up of different kinds of rock, and the Apollo samples seemed to confirm that. Anorthosite, a rock made almost entirely (more than 90 percent) of one mineral, plagioclase feldspar, seemed abundant in the highlands, whereas dark, solidified flows of basalt lava were the bedrock of the "seas."

But studies by Bradley L. Jolliff and his colleagues at Washington University in St. Louis, which integrate the latest data from orbiting sensors with the data from lunar samples, reveal a far more complicated Moon. Morphology and color do not tell the entire story of the surface composition. The concentrations of iron and thorium, for instance, have proved useful in distinguishing rock types from one another and in monitoring geochemical processes.

Those and other chemical data partition the Moon into several distinctive chemical provinces. The basalt making up the maria is rich in iron. A large swath of the near side of the Moon incorporates high concentrations of thorium. Most of the Moon's iron-rich basalt maria occur on the near side as well, where they alternate with highlands having only moderate concentrations of iron. But a large region of rugged highlands on the far side, as well as heavily cratered patches on the near side, are poor in both iron and thorium. Those regions are battered portions of the ancient lunar crust, and they have been a key focus of the most recent efforts to understand the early history of the Moon.

One striking area is a huge impact crater on the far side, the South Pole–Aitken basin (SPA). It measures some 1,550 miles across, and its floor is eight miles lower than the surrounding highlands. SPA has a markedly different composition from the rest of the far side of the Moon. It is particularly rich in iron and thorium, which, because SPA is so deep, might reflect the composition of the Moon's interior.

The new data from space probes and lunar meteorites have helped planetary scientists refine their understanding of the Moon's origin and geologic history. A successful theory of lunar origin must explain two key facts. One is all the spinning of the Earth and the Moon. The Earth rotates on its axis, and the Moon traces a circular path around the Earth, rotating once with each orbit.

The second fact to explain is the puny size of

the metallic iron core of the Moon. The Earth's core takes up about an eighth of our planet's volume. In contrast, as Lon L. Hood of the University of Arizona in Tucson and his colleagues have shown with magnetic data from the Lunar Prospector mission, the core of the Moon accounts for less than 1 percent of the Moon's volume.

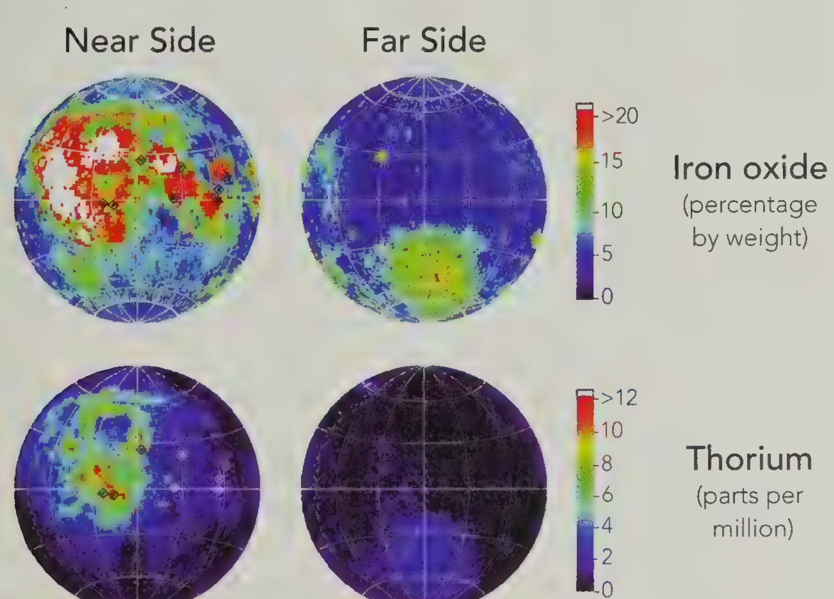
None of the traditional theories of how the Moon formed can explain those two observations in a straightforward way. According to the fission hypothesis, the primitive Earth was once spinning so fast (a day would have lasted just five hours) that a blob of it spun off, forming the Moon. But it takes extreme assumptions to get the Earth spinning that fast, and then to slow the Earth-Moon system down. No reasonable explanation has been forthcoming.

Other hypotheses are similarly flawed. According to the capture hypothesis, the Earth's gravity simply caught the Moon as it drifted too near. But planetary scientists have always viewed such a capture as implausible because it's so tricky to do dynamically. And, in any event, it does not readily explain why the captured Moon has such a small metallic core. In yet another scenario, the so-called binary planet, or co-accretion, hypothesis, the Earth and the Moon all formed at the same time by the accretion of small bodies. But that scenario, too, requires a particular and somewhat unlikely balancing of forces to make it happen, and it, too, does not explain why metallic iron is so much less abundant in the Moon than it is in the Earth.

The flaws in the traditional hypotheses led planetary scientists to seek other explanations for the Moon's origin. A new idea blossomed in 1984, at a scientific conference held in Kailua Kona, Hawai'i. The seeds of the idea had been planted a decade earlier by William K. Hartmann and Donald R. Davis of the Planetary Science Institute in Tucson, and independently by Alastair G. W. Cameron of the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, and William Ward of the Jet Propulsion Laboratory in Pasadena, California. The bold, new idea imagines a dramatic and violent birth for the Moon during a collision between Earth and an object about the size of Mars.

That so-called giant-impact hypothesis does explain the two key observations about the Earth-Moon system. To get the right amount of angular momentum into the system you need a big, off-center whack. The giant impact could have provided that whack. The hypothesis also explains why the Moon has such a small core. Computer simulations of the giant impact, made both by Cameron and independently by H. Jay Melosh of the University of Arizona and his colleagues, show that both bodies would melt in the impact and the dense core of the impactor would fall as blobs of melt into the similarly liquefied iron core of the Earth. The ejected material—the proto-Moon—would be nearly (though not quite completely) devoid of metallic iron, and so it would form primarily out of the rocky mantle materials surrounding the cores of the impactor and the budding Earth.

The giant-impact hypothesis has become the reigning favorite among planetary scientists. Computer models by John E. Chambers, now at the NASA Ames Research Center in Moffett Field, California, suggest that the Earth formed from smaller objects in a relatively narrow, ring-shaped zone centered at the present Earth-Sun distance.



Concentrations of the elements iron (in the form of iron oxide) and thorium are useful indicators of the geochemical "provinces" of the Moon. Both elements are far more common in the maria—the lunar "seas" that represent the outflow of the magma onto the satellite's surface—than they are in the rocky, mountainous regions known as terrae. The maria are readily visible in the two false-color maps of the near side of the Moon. The maps of the far side have far less of both of those elements; the highlands there are made up chiefly of a calcium-rich feldspar. One glaring exception to that general rule appears around the south pole on the Moon's far side: the South Pole–Aitken basin. The high levels of iron and thorium there suggest to geologists that the deep interior of the Moon is rich in both elements.

The giant impactor would have formed in the same region, giving it a similar chemical composition. Any further differences between the Earth and the Moon can be accounted for by the giant impact. For example, chemical reactions would have created new lunar compounds during the event, and the hot blob of molten matter would have evaporated the Earth's most volatile elements into space.

In spite of the success of the giant-impact theory and the insights it gives about what the Moon is made of, the bulk composition of the Moon remains uncertain. The thickness of the lunar crust, the composition of the lower crust, and the composition of the mantle beneath it are all blanks.

Most of the rock fragments in the first soil samples returned from the Moon by Apollo 11 in 1969 were pieces of basalt from the lava flows underlying Mare Tranquillitatis (the Sea of Tranquility). The dark soil included some small, whitish fragments of anorthosite. Studying those samples John A. Wood of the Smithsonian Astrophysical Observatory made three bold and imaginative inferences from the white bits of rock. First, he decided they had nothing to do with the underlying basalt; instead, he maintained, they came from the highlands, which, he guessed, were dominated by anorthosite's main mineral component, plagioclase feldspar. (The Apollo missions had not yet ventured to the highlands.)

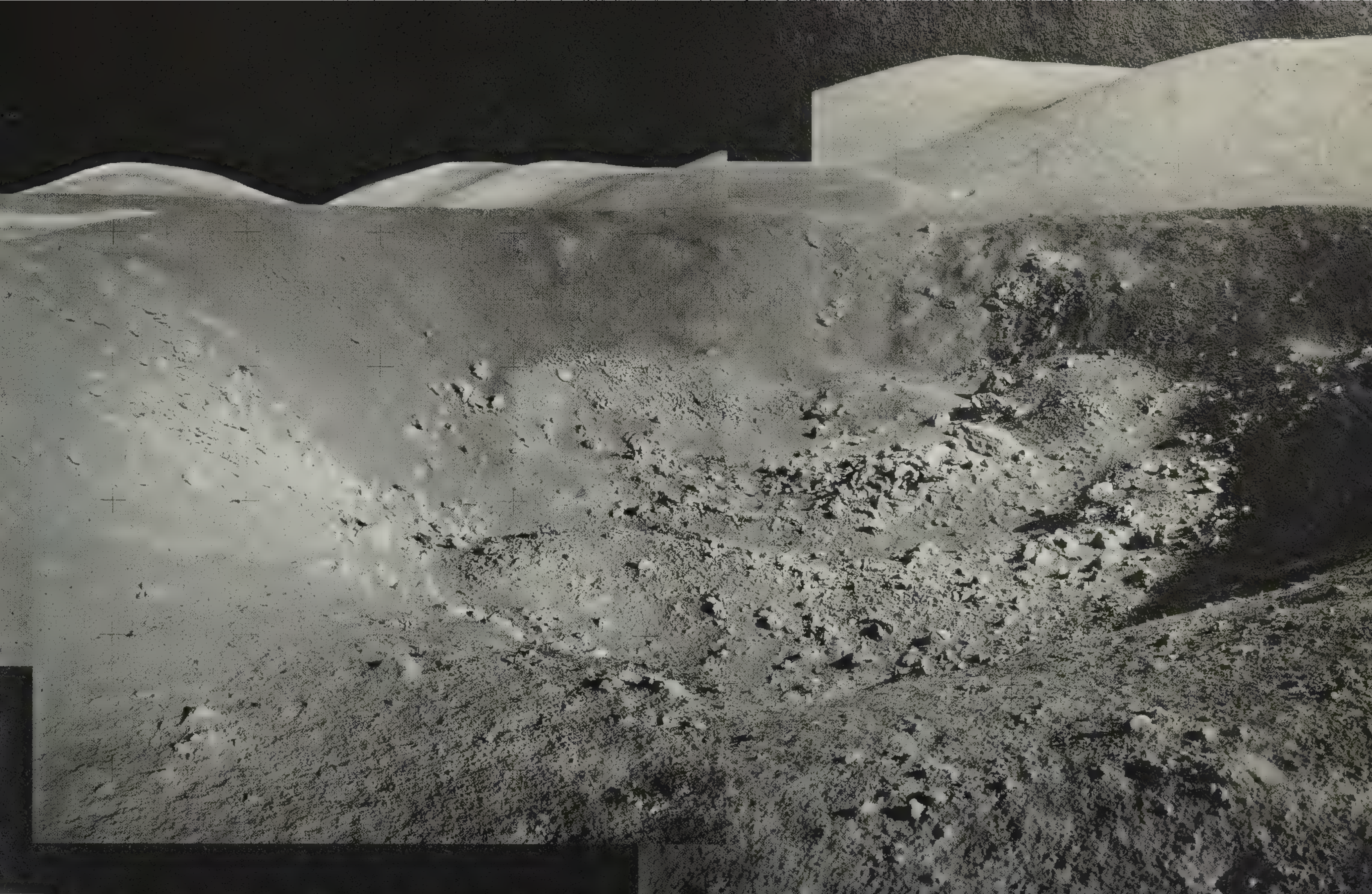
Wood's second audacious—and completely unsubstantiated—claim was that all the lunar highlands were made of the rock anorthosite. How, he wondered, could that have happened? He thought about how magma slowly cools beneath the Earth's surface, about how the minerals in the magma can separate from each other according to their densities, just as oil floats on vinegar in salad dressing. That line of thinking led Wood to the third of his suggestions: that plagioclase feldspar floated to the surface of a Moon-encircling ocean of magma to form the initial rocks of the lunar crust.

Evidence in favor of Wood's speculations soon began to accumulate. Anorthosite rocks were found in abundance in 1972 at the Apollo 16 landing site, in the lunar highlands. Geochemists noted that some chemical characteristics of mare basalt lavas were complementary to the chemistry of highland anorthosites. For example, the mare basalts were depleted in aluminum and europium, whereas the anorthosites were loaded with aluminum and enriched in europium. Those findings suggested that the magma in the deep interior regions of the Moon, where the basalt lavas formed, were part of the same magma in which plagioclase

feldspar floated to give rise to the anorthosites. The complementary chemistry then arose as the magma differentiated according to the density of its crystalline components. Taken together, this line of thinking had an astonishing implication: because the mare basalts formed at depths of hundreds of miles, the magma ocean must have been hundreds of miles deep.

The most basic piece of confirming evidence for Wood's theory, however, was still lacking: proof that the ancient highlands are made of anorthosite rock. In 1994 the Clementine mission and Paul G. Lucey, my colleague at the University of Hawai'i, solved that problem. The orbiting *Clementine* spacecraft photographed the entire lunar surface. Lucey then calibrated the photographs against the "ground truth" from the Apollo landing sites and the returned soils, and so figured out how to convert the intensity of light reflected by a particular patch of ground into a measure of the concentration of iron present there.

But what could measuring iron concentrations have to do with finding anorthosite in the lunar highlands? None of the minerals known as feldspars contain iron. But when plagioclase feldspar accumulated in the initial melt to form anorthosite rock, small concentrations of iron-bearing minerals could also be frozen into the



The astronaut and geologist Harrison Schmitt (standing next to the lunar rover at the left) photographs the 360-foot-wide Shorty Crater, as he and the crater are in turn photographed by his crewmate Eugene Cernan. The crater and the mission's landing site both lie on the eastern edge of the Sea of Serenity, which appears on the upper-right face of the Moon when seen from the northern hemisphere of Earth. At the Shorty Crater the two astronauts discovered orange soil, colored by beads of glass created during volcanic activity some 3.7 billion years ago. Cernan made the photograph during the Apollo 17 mission in December 1972, the final Apollo mission to the Moon.

rock. Hence anorthosite could contain a few percent iron by weight. The maps derived from the Clementine data show huge regions of the highlands, particularly on the far side, that are between 1 and 4 percent iron by weight, with an average of about 3 percent. The finding confirmed a central tenet of the magma-ocean hypothesis: the original crust of the Moon was anorthosite rock formed out of plagioclase feldspar floating in a dense global magma.

The lunar highlands are a cratered mess; piles of rubble are heaped around thousands of craters, as wide as hundreds of miles across, that lie one right next to another in silent testimony to an ancient bombardment of the Moon. About forty-five craters are huge circular basins at least 200 miles across, the low centers surrounded by concentric mountain ranges. These mountain ranges attest to the violence of meteoroids; almost all the samples brought back from them are either greatly deformed or are part of complex fragmental mixtures of rock called breccias.

When did that massive pummeling take place? It must have happened before the visible maria formed, because they are not covered or scoured by the materials ejected from the huge craters. Samples indicate that the oldest maria are slightly less than 3.8 billion years old, so the bombardment occurred between 4.5 billion years ago (about the age of the Earth and Moon) and 3.8 billion years ago. Before the Apollo samples became available, many planetary scientists had favored an early, intense bombardment associated with the late stages in the accretion of the planets. The bombardment would have decreased rapidly after the Moon formed, as Earth, the Moon, and the rocky planets swept up the smaller chunks of material still orbiting the Sun. By 3.9 billion years ago a relatively clement period would have prevailed.

But studies of the lunar samples pointed toward an alternative scenario, first put forward in 1975.

Fouad Tera and Gerald Wasserburg of Caltech radiometrically dated rocks from the lunar highlands. The data led them to suggest that the impact rate declined rapidly soon after the Moon formed, but then returned to spectacularly high levels around 3.9 billion years ago. Such a deluge would have affected the Moon and perhaps the rest of the solar system, or at least its inner region, between Mercury and Mars. The dramatic increase in impact rate 3.9 billion years ago became known as the cataclysm. There was a brief flurry of interest in the idea, but then it was essentially dropped until 1990, when the late Graham Ryder of the Lunar and Planetary Institute (LPI) in Houston revived it.

Impact craters or basins can be dated only by examining the materials melted during the impact. (The resulting rocks are known as impact-melt breccias, or impact melts for short.) Ryder and others identified groups of impact melts by their chemical compositions and showed that different groups had different ages. By associating specific groups of impact melts with specific basins and applying the principles of stratigraphy, lunar scientists determined that several basins were formed later than 3.9 billion years ago, in the ensuing 100 million years. In short, the newly analyzed data showed that these basins could have been formed in the cataclysm.

A rock collected from one lunar basin could test the cataclysm hypothesis.

There has been no lack of imagination in devising models that might explain the cataclysm. Perhaps a large asteroid, say the size of the asteroid Ceres, 600 miles across, was blown apart in a collision, and its fragments showered the inner solar system. Or perhaps a passing star perturbed the orbits of comets in the Oort cloud (a swarm of trillions of comets that surrounds our solar system), and several comets came crashing into the inner solar system. Or perhaps objects from the Kuiper belt were the culprits, the rocky bodies—of which Pluto is an example—that circle the sun outside the orbit of Neptune. Uranus and Neptune might have formed at about the time of the suspected cataclysm, and maybe they dragged Kuiper belt objects into collision courses with the other members of the solar system.

The cataclysm has clearly become an important concept. The rub is that not everyone agrees with the idea that several huge basins formed in one relatively narrow, 100-million-year interval. Some geochemists argue that the sites of the Apollo landings were all reworked by the immense impact that created the Imbrium basin. Mare Imbrium, which makes up the right eye of the man-in-the-Moon, is 725 miles across. Its formation would have drastically altered the lunar surface. Thus, people skeptical about the cataclysm argue that the age measurements of basins that cluster close to the same time period actually reflect that one event: the formation of one relatively young basin stopped and reset the geological clocks that record the ages of the other basins allegedly created in the cataclysm.

One difficulty with the skeptical argument is that there are subtle, but significant, compositional and age differences among impact melts. To be certain, geochemists need samples from basins that were clearly not affected by the Imbrium event.

One possible source of such untainted data are Earth's lunar meteorites. The ones originating in the lunar highlands could be identified by their chemical makeup. Barbara A. Cohen (now at the University of New Mexico in Albuquerque) and her colleagues at the University of Arizona extracted pieces of impact melt from several lunar meteorites and measured their ages. These meteorites most likely come from regions of the far-side highlands far from Imbrium, and so are untainted by Imbrium debris. None of the samples was older than 3.9 billion years, a result consistent with a spike in the impact rate 3.9 billion years ago.

Still, it is scientifically preferable to collect samples of the melt that formed during the creation of a specific lunar impact basin. A prime candidate for a collection site is the South Pole–Aitken basin, which lies virtually opposite Mare Imbrium—hence as far from Imbrium's contaminating influence as possible. SPA is the oldest basin on the Moon, and determining the ages of impact melts from SPA could test the cataclysm hypothesis. If SPA is much older than 3.9 billion years—say, 4.3 billion years old—the cataclysm hypothesis becomes less compelling. Basins would have formed between 4.3 billion and 3.8 billion years ago, not in the relatively short time hypothesized for the cataclysm. In contrast, if SPA is 3.9 billion or perhaps even 4 billion years old, the cataclysm hypothesis gains favor.

We time travelers have pieced together an intriguing story about the Moon, a story with great implications for our understanding of the formation and geologic histories of the rocky planets—what happened to the Moon most likely happened to all the rest. But planetary scientists also tell many variations on the story. To settle on one version, people will have to return to the Moon.

The maria of the moon's near side give way to the heavily cratered highlands of the far side. The large dark area near the lunar horizon at roughly eleven o'clock in the photograph is the Sea of Crises. Nearer the center, at roughly 10:30, is the Sea of Margins; at roughly 9:30 is Smith's Sea. The two seas lie along the longitude line demarcating the "light" and "dark" sides. The photograph was made from roughly 1,000 miles above the lunar surface by the astronaut Kenneth Mattingly, during the Apollo 16 mission.

The world's space agencies are not unaware of the opportunities: China, Europe, India, and Japan all have plans to send robotic scientific missions to the Moon. An extensive study by the U.S. National Academy of Sciences placed the highest priority on bringing samples back from the South Pole–Aitken basin. Analyses of these samples would help determine the bulk chemical composition of the Moon; test ideas for planet formation and lunar origin; provide more details of how impacts excavate huge holes on planetary surfaces; and shed light on the bombardment history of the solar system. In short, it would help answer the question: How did the universe give rise to us? □

The lunar photographs accompanying this article were taken during the NASA Apollo missions and were reproduced by photographer Michael Light. They are on permanent exhibit at the Rose Center of the American Museum of Natural History in New York City.

The quipu served as a kind of database among the Incas. The knots, colors, and lengths of the cords encoded information about people, land, and crops. This quipu is from the Chancay culture, which flourished in a coastal valley of Peru from the thirteenth until the fifteenth centuries.

The Varieties of Mathematical Experience

Ethnomathematics is a powerful tool for understanding other cultures.

By James V. Rauff

The Incan *quipu* is an unusual object, an assemblage of slender, knotted cords tied along a thicker, main cord. The cords are dyed a variety of colors: when it's bundled up, a quipu looks like a multicolored mop; when it's spread out, it resembles a long rope necklace or a grass skirt. The quipus of the ancient Incas of Peru encoded a wide range of data about people, land, and crops for the government bureaucracy. The code was efficient and compact: the color, number, and relative spacing of the cords, and the number and type of knots tied into each cord, all held significance. A quipu might include as many as 2,000 cords, in some fifty or sixty different colors. I won't venture to estimate the storage capacity of a quipu in bits or bytes, but the system was, in its unique way, a pre-Columbian database for the Andes—an artifact of a mathematical tradition that developed entirely outside Western models.

Marcia Ascher, emerita professor of mathematics at Ithaca College in New York, and her husband Robert Ascher were instrumental in deciphering the code of the quipu (their book *Code of the Quipu: A Study in Media, Mathematics, and Culture* was published in 1981). Since then Marcia Ascher has focused her considerable analytic skills on a whole range of similar mathematical artifacts and concepts outside mainstream Western culture. Her latest offering, *Mathematics Elsewhere: An Exploration of Ideas across Cultures,* is a collection of essays on mathematical concepts in use by

small-scale, traditional societies: a series of reports from an explorer "in the field." Ascher both examines the nature of the mathematics put into practice by individual societies and considers how those non-Western mathematical concepts fit into and express the ethos of the cultures that gave rise to them.

Ascher's book is at once a scholarly progress report and an introduction for the curious general reader to a relatively new area of study known as ethnomathematics. The field, which has emerged in the past two decades, lies at the intersection of anthropology, education, and mathematics. For the ethnomathematician, all signs of counting, measuring, designing, patterning, modeling, sorting, or reasoning are evidence for the existence of mathematical ideas. Such ideas, whether implicit or explicit, past or present, and no matter what the cultural setting, are grist for the ethnomathematician.

Among the Iqwaye people of Papua New Guinea, for instance, fingers, toes, and the spaces between toes are tools for counting to numbers much higher than 10 or 20 or 28; instead, they form the basis of a sophisticated numbering system that can count to numbers of indefinitely large size. Among the Cayuga of New York state, the rules of a game of chance called *dish,* which were documented in the late nineteenth century, clearly demonstrate that the players understood the laws of probability. The assigned point values for each possible outcome of the game closely corresponded to their associated probabilities—at least as clearly as the rule in poker that four-of-a-kind beats a full house.

In the brief history of ethnomathematics, two international conferences on the topic have already been convened, the first in Granada, Spain, in 1998, and the second one last year, in Ouro Preto, Brazil. The International Study Group on Ethnomathematics claims membership from around the world. The Brazilian mathematician Ubiratan D'Ambrosio, emeritus professor of mathematics at Brazil's State University of Campinas, who is generally credited with defining the field, has called it a "research program in the historical and epistemological foundations of mathematics with pedagogical implications." That entails, in part, charting the diversity among groups of people in the realm of mathematics: the ways numbers are understood and conceived, the methods of reasoning, and the systems people adopt to model and find patterns in their own social and natural environments. D'Ambrosio's program aims at compiling a universal history of mathematics that includes contributions from every culture on the planet.

Mathematics Elsewhere: An Exploration of Ideas across Cultures
by Marcia Ascher
Princeton University Press, 2002; $24.95

Mathematics Elsewhere fits squarely into D'Ambrosio's program, and she organizes the bounty of cases she cites around the themes of divination, time, maps, relationships, and art. From Madagascar, for instance, she describes a divination practice that has endured for four centuries, in essentially the same form, among members of the island's diverse ethnic and sociopolitical groupings. Madagascans seeking advice and guidance consult an expert, known as an *ombiasy,* in a divination system called *sikidy.* The diviner grabs a fistful of the seeds from a local tree out of a bag and makes a column of four random piles. He then removes the seeds from the piles two at a time, until each pile is reduced to either one or two seeds. He then repeats the process three more times, each time placing the new column of piles to the left of the preceding column. In the end he has sixteen piles of seeds before him, each containing either one or two seeds, arranged in four columns.

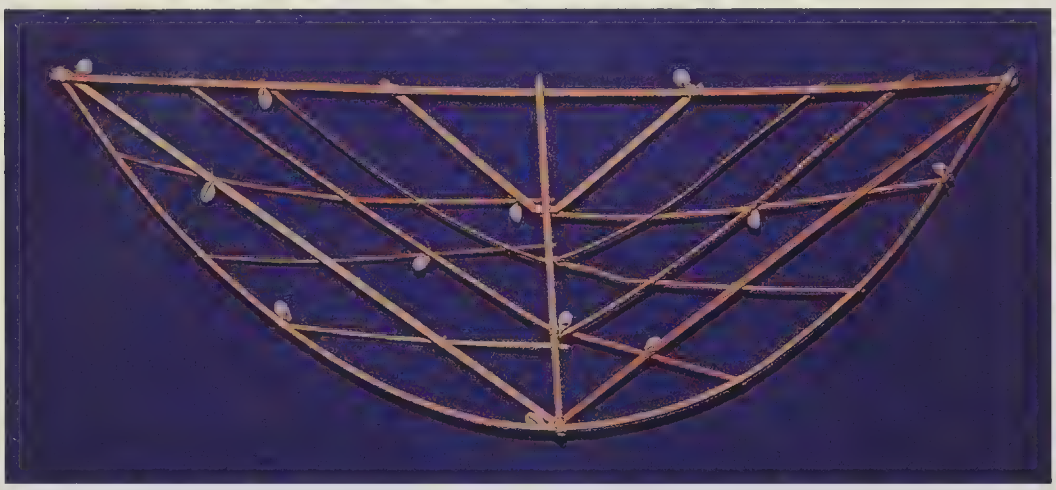
The diviner then applies a single rule to selected pairs of the sixteen piles. If both piles in a pair are the same size, he makes a new two-seed pile. If the two piles have different sizes, the diviner makes a new one-seed pile. He then applies the same rule to certain pairs among the new piles he has just created. In the end, he constructs what Ascher calls a tableau of sixteen columns, with four piles of seeds in each one. The tableau is then "read" by the diviner—"where the logical algebra leaves off and the attribution of meaning begins," as Ascher notes.

The rule for combining pairs of piles, as Ascher points out, is identical with the XOR ("exclusive or") operation familiar to computer scientists. (The name comes from the logical operation of combining two statements into one with a prescribed meaning of the word "or"; by convention, the resulting combined statement is said to be true if one and only one of the original statements is true. If both statements are true, or both are false, the combined statement is considered false.) Ascher also explains in great detail that by combining the pairs in the particular order he follows, the diviner incorporates the procedure known in Western mathematics as even-parity checking, which helps ensure that no calculating mistakes are made along the way.

Ascher's approach to the *sikidy* system is typical of many ethnomathematical studies. A particular cultural artifact is shown to have mathematical properties related to mathematical systems in the West (in this case, to some of the ideas associated with computers and cryptography). But her purpose is not to compare the diviner to a computer scientist; rather, her aim is to demonstrate that the mathematical techniques we in the West think of as modern and advanced can arise independently of Western influence, and in unexpected places. Such a demon-

...ation is of obvious interest and relevance to historians of mathematics, but its scope has a much wider appeal. Ascher offers a new way of understanding the customs and traditions of non-Western people, adding the lens of mathematics to those of literature, anthropology, and sociology. When one views cultural practices from a mathematical perspective, understanding is deepened, vague descriptions are clarified, and the sophisticated conceptual underpinnings of those practices are revealed.

ethnomathematics in their own work. One study group, for instance, which calls itself the Ciulistet, invites elders from the Yup'ik people of western Alaska to collaborate with native teachers and University of Alaska professors on, among other things, the design of educational materials for Yup'ik children. One outcome of their work has been to present counting to the children in accord with the way Yup'ik culture itself visualizes the operation. Another educational innovation spurred by ethnomathematics



Latticework "stick charts," such as the one pictured above, represented ocean movements and, sometimes, the position of islands. They were used as navigational aids by Marshall islanders and others throughout Micronesia.

It is worth emphasizing that in traditional systems such as the ones Ascher describes, there is no distinction between pure and applied mathematics. Ethnomathematicians therefore find it useful to contrast "global," or Western, mathematics with the "local" mathematical knowledge of individual cultures. Local mathematics can be detected, for instance, in the work of artisans and craftsmen, as well as in the lives of farmers, fishermen, healers, storytellers, and street merchants. It manifests itself in beadwork, games, hairstyles, maps, painted designs, songs, and woven goods. Local mathematics cannot be separated from its social setting; it functions as a part of the total cultural picture.

That emphasis on the total cultural perspective has led mathematics educators working in non-Western settings to recognize the importance of

is the "dancing numbers" project, led by James Barta, an associate professor of early childhood education at Utah State University in Logan, Utah. Among other projects, Barta is working with elders of the Ute people in Colorado and Utah on methods of teaching symmetry and basic arithmetic through beadwork patterns.

Numerous similar projects for teaching Western mathematics in traditional settings are under way from Papua New Guinea to the inner cities of the United States. All recognize that an understanding of local mathematical knowledge can both validate a child's native culture and provide a bridge to modern Western mathematics.

Ascher proves adept at illuminating the connections between local and global mathematics. After her tour de force on "the logic of divination," Ascher turns her attention to some of the fascinating ways people have developed of keeping track of time. Calendars have long been a staple of ethnomathematical research, but *Mathematics Elsewhere* offers some fresh twists. Most appealing is the case of the Rato Nale ("priest of the sea worms"), the highest-ranking priest of the Kodi people, who live on the island of Sumba in Indonesia. The sea worm in question is a marine annelid *(Leodice viridis)* that spawns only once a year. The Rato Nale is charged with predicting the event, which marks the beginning of a series of local festivals whose observance must also correspond to a lunar-solar calendar. Ascher explains how the priest, who is responsible for the yearly calendar arrangements, draws both on astronomy and seasonal environmental clues to mark time in a way that is also faithful to the cycles of the Sun and the Moon. Her description provides an intriguing case study in how traditional customs select, define, and reinforce the interactions between nature, culture, and time.

On the Indonesian island of Bali, Ascher focuses on the so-called Javanese-Balinese ritual calendar (also known as the Pakuwon) and its magical and dizzying sequences. Numerous cultures use calendars that mark off multiple cycles, she notes, but the Pakuwon calendar, with its ten concurrent cycles, is uniquely intricate. Somewhat confusingly (to Western ears) the cycles are known as "weeks." The Pakuwon calendar assigns each day of the year to "weeks" made up of ten days, nine days, eight days, and so on, all the way down to a one-day "week." In other words, every day has ten names in the Pakuwon calendar, one for its position in each of the ten "weeks."

One reason for all this cycling is that many important Balinese events fall on particular days of certain kinds of "weeks": for example, the three-day week determines the market schedule. Spiritual matters are also re-

flected in the calendar; a son or daughter's date of birth within the eight-day week, for instance, suggests the child's identity in a previous incarnation. A year in this calendar—a "full supercycle" of all the weeks, as Ascher explains—is 210 days long. The period is a kind of mathematical compromise: it is the shortest period that includes an integral, or whole, number of weeks of one, two, three, five, six, seven, and ten days. (In terms familiar to Western high school students, the least common multiple of 1, 2, 3, 5, 7, and 10 is 210.)

But of course "weeks" of four, eight, or nine days do not fit evenly into such a "full supercycle"; that would require a supercycle twelve times as long as 210 days, or nearly seven "solar" years—an unwieldy length of time for a calendar. Instead, to ensure that even the weeks of four, eight, and nine days are all complete cycles, special adjustments are made. For example, two additional "seventh" days are added to the twenty-six complete eight-day cycles to enable them to fit evenly into the year.

This wonderfully complex calendar can be pictorially represented on a seven-row, thirty-column *tika,* a colorful calendric object that can be either painted or carved on wood or printed on paper. Ascher explains how visualizing their calendar as a *tika* enables the Balinese to solve, in their heads, complicated questions about the occurrence of specific calendar days. One point she emphasizes is particularly useful: the Pakuwon's cycles of weeks neither measure elapsed time nor coordinate with solar or lunar cycles. Rather, they represent the myriad cyclic forces in Balinese cosmology, since each calendar day is literally marked by a multiplicity of intersections among concurrent cycles. Divorced from physical cycles, Ascher notes, the calendar "becomes a creative expression of abstract mathematical ideas," yet it also functions as an expression of the "logic of interlinked cycles" pervasive in the Balinese culture.

Ascher's next stop is the Marshall Islands, in the western Pacific Ocean, where she explores the mapmaking genius of its seafaring people. Western navigators are accustomed to finding landmasses by their shapes and positions on maps overlaid with a grid system: latitude and longitude. We read maps of the sea that incorporate symbols for prevailing winds, currents, and depths—characteristics we regard as essential to navigation. But the Marshall islanders take little interest in those factors—what count instead are the shapes and orientations of the ocean swells that break around islands.

Ascher begins her account of Marshallese "wave piloting" by describing the use of the *mattang,* a stick-chart training device for prospective navigators that represents the general pattern of how ocean swells break around an atoll. She then explains the kinds of stick-chart maps that show real ocean-swell patterns: *rebbelith*s, which chart either the entire archipelago or particular atolls within it; and *meddo*s, which are maps of smaller regions. Both kinds of maps highlight the culturally salient features of the Marshallese seascape—which, from a Western perspective, represent a truly unique way of modeling the world.

Another example of an unusual way of modeling the world—in this case, the interactions within a community—emerges among Basque villagers of the Sainte-Engrâce region, in the French Pyrenees. Here, on Ascher's account, social relations are conceptualized according to a circular model known as *bardin-bardina,* or "equal-equal." One might think the concept of equality, one of the most basic of mathematical relations, would be impervious to cultural variation, but Ascher soon puts that notion to rest.

Among the villagers, a community is understood as, literally, a circle of households. From the center of that conceptual circle, each household has a "left" neighbor and a "right" neigh-

bor. The concept of equality is realized concretely, in a system of tasks that rotate among the households, and accomplish the community's sheep-herding and cheese-making work. The sheep-herding tasks, for instance, are explicitly ranked according to their prestige and authority. The rotation then ensures that no status hierarchy is permanent, and that every household undertakes every task, from highest to lowest in status, at some point in the process. Equality in this system, Asher argues, is "a dynamic process of interaction involving rotation, serial replacement, and alternation."

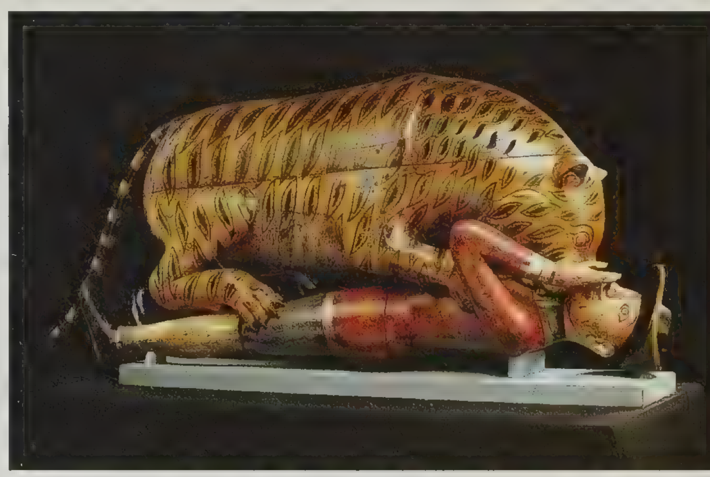
Mathematics Elsewhere is a challenging book for nonspecialists, with a high proportion of its content devoted to traditional mathematics. Part of what makes the volume accessible to the general reader, though, is Ascher's evident love for her subject. The mathematics she includes clearly serves a larger purpose: to enhance and illuminate the anecdotes that are the foundation of genuine cultural understanding. Ascher never loses sight of the people who have created the artifacts and ideas she explores. And, as she frequently reminds the reader, she is bound by her own culture and her own audience to use Western mathematical terminology to describe the mathematics of others. She is at pains to remain as true as possible both to the mathematics and to the anthropology.

The great value and contribution of ethnomathematics is that it shows mathematics as a human endeavor, arising from peoples' needs and desires to understand and find patterns in their physical, social, and spiritual worlds. Ethnomathematics asks all of us to recognize the diversity in those patterns, and in the ways people understand their world. In short, ethnomathematics asks us to see the mathematics elsewhere.

James V. Rauff is a professor of mathematics at Millikin University in Decatur, Illinois.

Monster of God: The Man-Eating Predator in the Jungles of History and the Mind
by David Quammen
W.W. Norton & Company, 2003; $25.95

David Quammen likes to visit places on the wave crests of ecological change. One of his previous books on natural history, *The Song of the Dodo,* dealt with island biogeography and endangered species. *Monster of God,* his latest environmental travelogue, is filled with place names that few readers will recognize: Garrangali, a swampy expanse in Arnhem Land, on the remote northern coast of Australia, where a complex network of channels and underground tunnels provides a unique breeding ground for saltwater crocodiles; the Gir forest in India's Gujarat state, northwest of Bombay, whose cattle-herding inhabitants, the Maldharis, maintain an uneasy truce with the last remaining lions on the Indian subcontinent; Braşov, in the rugged Carpathian Mountains of southeastern Romania, where *Ursos arctos,* the European equivalent of a grizzly, is one of two major predators (the other is the human sports hunter); and the Bikin Valley, in the foothills of the snowy Sikhote-Alin Mountains of far eastern Russia, where the Amur tiger considers trappers' dogs a sublime delicacy.



Tiger mauling a British officer; wooden sculpture, India, c. 1790

Quammen's stated purpose is to give his readers some feeling for what it means to be part of the food chain, an "awareness of being meat." Most people nowadays are city dwellers, to whom meat is a substance between two halves of a sesame-seed bun, and for whom predatory animals are just curiosities to be exhibited or pests to be exterminated. But to the residents of Arnhem Land, Gir, Braşov, and Bikin, predators are animals that hunt people—and sometimes eat them. Life for such folks, one imagines, is not the predictable routine of a nine-to-five commuter, but rather a regimen of vigilance punctuated with moments of sheer terror, like a continuous rerun of *Jaws* with real blood and no popcorn.

Needless to say, Quammen has dug up some teeth-clenching stories and met some memorable characters. A few, such as Val Plumwood, an Australian philosophy professor, know firsthand what it's like to be prey. In 1985 a crocodile "somewhere between eight and twelve feet" snatched her from her canoe and flung her about in a series of the frenzied "death rolls" with which crocs try to drown and dismember their prey before swallowing the pieces. Plumwood managed to disengage from the jaws of the croc, drag herself to shore, hike several hours to reach civilization and rescue, and eventually convey her experience in several academic articles, in one of which she relates the "total terror, total helplessness, total certainty, experienced with undivided mind and body, of a terrible death," which many less fortunate victims must have faced.

Most of Quammen's informants, however, are naturalists, hunters, farmers, and herders, who can offer more evenhanded opinions on predators and their possible peaceful co-existence with humankind.

Both the bear and the crocodile populations seem to be hanging on for now, in part, ironically, because some balance has been reached between protecting them and cultivating them for sport, meat, and leather. Romania's one-time dictator, Nicolae Ceaușescu, for instance, ordered bears to be protected so that he could shoot them himself, which he did by the dozen. There's some evidence, Quammen notes, that predators thrive under despotic social regimes, though not because tyrants are environmentally aware.

The most endangered predators Quammen meets are Indian lions, which were once protected by Indian nabobs but now threaten local livestock and compete with the populace for scarce resources. Yet residents of the Gir forest respect the creatures that endanger but also enrich their lives: "I've spent so many hours of my life thinking about lions," Quammen describes one villager telling him. "Slowly I came to realize . . . that this landscape belongs to the lions if it belongs to anyone. 'And if they can't stay here, where will they go?'" One hopes—for all these lions, tigers, bears, and crocs—not the way of the dodo.

Meteorites, Ice, and Antarctica: A Personal Account
by William A. Cassidy
Cambridge University Press, 2003; $30.00

Like a cruising car on a buggy summer night, the Earth, as it orbits the Sun, continually collides with small flying objects. The interplanetary debris is made up of fragments of disintegrated comets and shards of shattered asteroids, ranging from gnat-size specks of dust to house-size rocks and larger. Meteor watchers see the objects fleetingly as they enter the atmosphere, heating the air around them to incandescence before, in most cases, they are reduced to airborne ash. Out of an estimated hundred tons of mete-

oroids that collide daily with the Earth, only a minuscule fraction are large enough to make it to the ground before they burn up entirely. And of those, most fall unseen into the oceans or bury themselves in the ground, where they rapidly weather and become indistinguishable from terrestrial rocks.

Meteorites that happen to fall on the Antarctic ice sheet, however, meet a different fate. Buried by annual snowfalls after impact, they eventually become embedded in the two-mile-thick frozen mantle that overlies the continent. The ice both protects them from weathering and concentrates them in certain areas. As the ice flows at, let's say, glacial speeds downhill to the sea, meteorites are carried along with the flow. When the ice meets barriers such as mountain ranges along the way, the meteorite flotsam it carries is cast on the foothills like so many piles of driftwood on a beach, readily distinguished against the background of windswept snow. In such places, geologists have discovered, you can stretch out your hand in almost any direction and pick up a rock from another world.

William Cassidy, emeritus professor of geology and planetary science at the University of Pittsburgh, was the founder, in 1976, of the U.S. Antarctic Search for Meteorites (ANSMET), a pioneering effort to mine Antarctica's extraterrestrial bonanza. In nearly three decades of bone-chilling expeditions, Cassidy's team, along with similar groups from Japan and Europe, have collected more than 30,000 meteorites from the ice fields of Antarctica, more than fifteen times the number that had turned up elsewhere in the preceding two centuries.

For the casual reader, Cassidy provides an exciting picture of what it's like to be a meteorite hunter on the world's cruelest continent—from tales about surviving in hurricane-force winds that tear tents to shreds, to wry ruminations about answering the call of nature when the outside temperatures are cold enough to freeze your spit before it hits the ground.

But Cassidy's book is also full of authoritative science. Nearly all Antarctic meteorites, he notes, are splinters ejected from collisions between asteroids—those miniature worlds that have accumulated mostly between the orbits of Mars and Jupiter. Because asteroids are thought to be remnants of the material that formed the planets some 4.6 billion years ago, Antarctic specimens may carry important clues about how the solar system formed. The new wealth of data, however, has raised as many questions as it answers: the great variety of rock types among meteorites, for instance, indicates that the early solar system was not as uniform as astronomers once thought, either in temperature or in chemical composition.

Piece of the ALH 84001 meteorite from Mars, discovered in Antarctica.

The most remarkable finds on the ice sheet are a handful of meteorites that appear to be chunks from other large bodies in the solar system. In most cases they are rocks chipped off the Moon. Amazingly, though, some of them come from Mars [*see "Bolts from Beyond," by Donald Goldsmith, page 28*]. Cassidy describes in convincing detail how geologists can infer the planetary origins of such specimens (and, in some cases, even the lunar or Martian crater from which they were once ejected). And he gives a brief account of the most famous, and most controversial, meteorite of all, ALH 84001. According to some geologists, ALH 84001 con-

tains evidence of fossil life on Mars.

The controversy comes as no surprise: the study of meteorites preserved in ice fields is still a young science. So many specimens have accumulated so rapidly that analysis has yet to catch up with the available evidence. Yet Cassidy makes an excellent case for continuing the hunt for evidence. If a research enterprise can be measured by the excitement and beauty of its fieldwork, by the unique value of its data, and by the insights it yields into "big questions"—What are we made of? Where did we come from?—the study of Antarctic meteorites will remain a hot topic for many decades to come.

The Land of Naked People: Encounters with Stone Age Islanders
by Madhusree Mukerjee
Houghton Mifflin Company, 2003; $24.00

Global technology, for better or for worse, has made it possible for Lapland caribou herders and Amazon hunter-gatherers to watch reruns of *The Simpsons* with the cultural savoir faire of Los Angeles suburbanites. So it comes as a bit of a shock to read about the near-total isolation of the inhabitants of North Sentinel Island, a smallish member of the Andaman Islands chain, which lies some 750 miles south of Calcutta in the Bay of Bengal. The island's hundred or so inhabitants—the only remaining group of Andamanese still untouched by modern civilization—may still, like their fellow islanders a century ago, live as hunter-gatherers who wear no clothes, do not plant crops, and have only minimal use of fire (they cannot make it, but preserve hot embers to transport from place to place). They may even still be oblivious to the connection between intercourse and conception—just as they were in the nineteenth century, when travelers found that the Andamanese

(Continued on page 66)

nature.net

Hit Parade

By Robert Anderson

Meteorites are no longer the rare objects I once imagined them to be. The realization came to me soon after I began searching the Internet for information about them, and found Bill Arnett's "The Nine Planets" (www.nineplanets.org). Under the heading "Small Bodies," click on "Meteors, Meteorites and Impacts" for a quick rundown on the subject and a great list of links. At the link www.solarviews.com/eng/edu/micromet.htm, I was surprised to learn how easy it is to collect these extraterrestrial visitors by the hundreds.

I immediately went outside my home with a ladder and scooped up some of the fine silt that accumulates in my roof's rain gutters. My son helped me extract the iron bits from the dirt with a magnet, and voilà! We soon had a tiny pile of metallic particles to examine under a microscope lens. We discovered a number of good candidates for micrometeorites—primordial space dust that literally rains down on our roof. Another site, "Micrometeorite Webquest" (staff.harrisonburg.k12.va.us/~gcorder/mm_main.html), explains how to collect the celestial specimens directly from rainwater. Click on the hypertext "images" to get some idea of the size and shape of the objects my son and I were looking for.

Not surprisingly, meteoroids that create fireballs as they plunge through the atmosphere are more exciting to most people. Scroll all the way down the meteor page at "The Nine Planets," cited above, and under the heading "Impacts," click on "The Peekskill Fireball" (starchild.gsfc.nasa.gov/docs/StarChild/shadow/solar_system_level2/peekskill.html) to see a movie of one of the more spectacular events of its kind. Recorded in 1992, the fireball first appeared over West Virginia and broke up as it traveled. A sizable chunk of it crashed into a parked red Chevrolet Malibu coupe in the town of Peekskill, New York. You can see a piece of the famous specimen at "The R.A. Langheinrich Museum of Meteorites" (nyrockman.com/museum.htm). A link there will even take you to several photographs of the impacted Malibu.

You'll find an impressive list of links to sites that highlight comets and the asteroid belt—the source of most of the meteoroids that enter Earth's atmosphere—at NASA's "National Space Science Data Center" (go to nssdc.gsfc.nasa.gov/planetary/planets/ and click on "Asteroids and Comets"). Such giant asteroids as Vesta—the only asteroid from which terrestrial meteorites have been identified to date—are featured there

In spite of Hollywood's disaster-movie infatuation five years ago with colossal comet and asteroid impacts, public interest in the theme has waned. Unfortunately, the danger hasn't. But at another NASA Web site (go to impact.arc.nasa.gov/ and click on "OECD Report on NEO Hazard"), you'll find a report noting that an impact might be averted, given early enough warning. A complete guide for close-encounter paranoids can be found at NASA's "Near-Earth Object Program" (neo.jpl.nasa.gov), an excellent fount of NEO information of all kinds. Click on "Close Approaches" in the list on the left to see exactly how near the Earth some NEOs will approach in the future, and how close some have come in the recent past—a sobering experience.

Robert Anderson is a freelance science writer living in Los Angeles.

The Quest for the Golden Lens

A perfect alignment of massive objects would offer clues to the rate of cosmic expansion.

By Charles Liu

Pol Bury, *Fountain*, 1985

Long ago, Greek bards sang of Jason, a prince denied his throne unless he could provide his usurper with the Golden Fleece. Accompanied by a crew of young heroes, Jason set off on the great ship *Argo* to find this mysterious treasure, known to be in the land of Colchis, at the far eastern end of the Black Sea. The ancient Greeks immortalized their heroes in the stars, and many of the names that still designate stars and constellations today bring to mind Jason's mythical voyage: Carina, Puppis, and Vela represent the keel, stern, and sail of the *Argo;* Castor and Pollux, who accompanied Jason, became Gemini; and Hercules was one of Jason's mates.

Few, if any, modern astronomers lead the adventurous lives of Jason and his Argonauts, yet many of us are on a quest for something golden. The object we seek, of course, is no fanciful animal skin, but the rarest of cosmic coincidences: a "golden lens." Such a lens, created by the interaction of a quasar and a galaxy perfectly aligned with Earth, would enable astronomers to deduce one of the holy grails of astronomy: the Hubble constant, or the expansion rate of the universe.

Among the cosmic mariners seeking that prize is Somak Raychaudhury, an astronomer at the University of Birmingham in England. Observing in the X-ray part of the spectrum, he and his collaborators have been studying one promising celestial candidate, known as B1422+231. Despite its unglamorous name, the object would surely be elevated to the stuff of legend if, indeed, its lens were golden.

Einstein's general theory of relativity—the unification of space, time, and gravity—predicts the existence of gravitational lenses, including golden ones. Massive objects bend space-time around them, creating a dimple in space-time akin to the depression made by a bowling ball on a trampoline. Any light passing through such a dimple follows a curved path.

Now imagine a massive object that lies between a shining beacon and an observer. The massive object bends the light streaming at it from the beacon; if the alignment is right, the bent light can focus or magnify the original image of the beacon for the observer, perhaps to many times its original brightness. Hence the intervening object acts as a lens—not because it's made of glass or plastic, but because its gravity bends light.

Astronomers love gravitational lenses. They are sheer cosmic serendipity, but they provide us, free of charge, with a powerful telescope. Of course, you get what you pay for. First, they're quite rare; the Earth, the lens, and the light source have to line up just about exactly to give rise to a measurable lensing effect. If they deviate from a straight line by less than a thousandth of a degree of arc—about the width of a penny 3,000 feet away—the lens splits the magnified image into two or more irregularly spaced patches of differing brightness.

A second, and worse, problem with gravitational lenses is their blotchiness—they aren't created by smooth, regular massive objects, but rather by

complex, asymmetric ones such as galaxies and clusters, with scattered dense and sparse spots. Such a lens distorts as well as magnifies the light that comes through, sometimes creating multiple, twisted images of the objects behind it. It's more like looking through the thick glass bottom of a bottle of lemon soda than through a good magnifying lens.

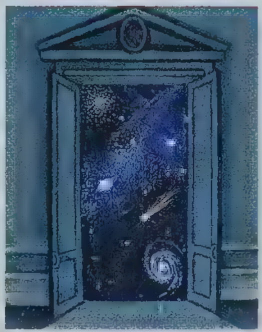
From such lemon bottles, though, astronomers have mixed excellent lemonade. The distortions themselves carry information about the universe. Imagine what happens if the light source changes its appearance—if, say, a quasar suddenly brightens with a new burst of energy. Each distorted multiple image of the quasar represents a different path taken by light through the dimpled space-time surrounding the lens, and some of those paths are longer than others. So first one image brightens—the one with the shortest path—then the one with the next-shortest path, and so on. The time between brightenings, it turns out, depends on two factors: the structure of the lens and the expansion rate of the universe—the Hubble constant. So all we need for a solid measurement of the Hubble constant, independent of the usual redshift of receding galaxies, is to identify a gravitationally lensed image of a flickering source with a near-perfect alignment, a readily measurable time delay, and a smooth, uncomplicated intervening mass. That's what gilds a gravitational lens.

With such stringent requirements, it's little wonder that Raychaudhury and his colleagues could have embarked on a quest that others had envisioned many years before their time but left still unfulfilled. Within a few years of looking, though, they thought they'd found a good candidate golden lens. The light from quasar B1422+231, which lies some 11 billion light-years from Earth, passes through a lens created by an intervening mass about three billion light-years from Earth. The lens gives rise to four detectable images of the quasar [*see photograph on next page*]. Furthermore, other astronomers had recently reported measuring a time delay in the brightening of two of those images.

With the orbiting Chandra X-ray Observatory, Raychaudhury and his colleagues found that the lensing object wasn't a single galaxy, but rather an entire group of galaxies, whose distribution of mass was relatively smooth and uncomplicated—one key requirement for a golden lens. Raychaudhury created 300 possible models of the shape of the lens, and simulated the lensing properties of each model.

THE SKY IN SEPTEMBER

By Joe Rao



Often elusive, fleet Mercury appears low in the eastern sky at dawn beginning around September 20. Rising about ninety minutes before sunup, it reaches its greatest elongation, or angular separation from the Sun (18 degrees west of our star), on the morning of the 27th. By early October the innermost planet returns to the obscurity of the Sun's glow. On the morning of the 24th, look low toward the east for a broad triangle outlined by Mercury, Jupiter, and the Moon; Mercury is below and to the right of the Moon.

By month's end Venus graces the evening, appearing just above the western horizon. Use binoculars to look for it between fifteen and twenty minutes after sunset.

Mars, just past its opposition of August 28, dominates the night sky. The orange-tinged planet is departing Earth's vicinity as rapidly as it arrived last month. As the distance between our home and Mars increases from 35 to 42 million miles this month, the planet fades from magnitude −2.9 to −2.1. Yet at the same time, viewing Mars becomes more convenient. The planet culminates at 12:55 A.M. local daylight time on the 1st, and at around 10:30 P.M. on the 30th. At those times the planet is about 33 degrees above the horizon (as seen from midnorthern latitudes), where its apparition is sharpest. Mars seems to follow the nearly full Moon across the sky during the night of September 8–9.

Jupiter emerges from the Sun's glare during the second week of September. At magnitude −1.7, the planet shines low in the east about an hour before sunup at midmonth. By the end of the month it's already up by 4:30 A.M. local daylight time. On the morning of the 24th, Jupiter rises above and to the right of a slender crescent Moon, and about 7.5 degrees above Mercury.

Saturn rises progressively earlier this month, appearing after 1:30 A.M. local daylight time on the 1st and coming up before midnight by the 27th. It shines in the constellation Gemini. The rings of the yellowish zero-magnitude planet tip about 25 degrees toward Earth.

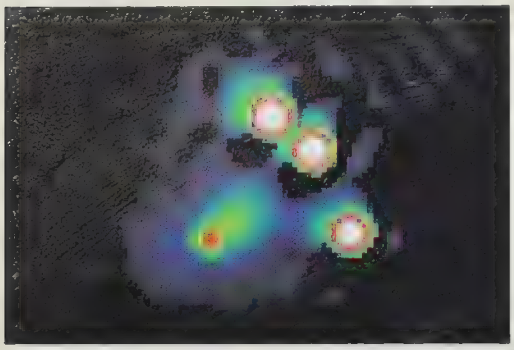
The Moon waxes to first quarter on September 3 at 8:34 A.M. and to full on the 10th at 12:36 P.M. Because this full moon is the one nearest to the autumnal equinox, it is designated the harvest moon. The Moon wanes to last quarter on September 18 at 3:03 P.M., and it becomes new on the 25th at 11:09 P.M.

The autumnal equinox occurs at 6:47 A.M. on September 23.

Unless otherwise noted all times are given in Eastern Daylight Time.

From the simulations he calculated the time delays that would result.

Unfortunately, the simulations showed that only two of the four images would yield measurable time delays. Moreover, one of those two images is too faint for its brightening to be feasibly measured with current technology. The conclusion: B1422+231 is indeed a fascinating gravitational lens system, but it's not quite golden.



False-color image of the gravitational lens system B1422+231. Each of the four brightest points of light represents a single quasar some 11 billion light-years from Earth; the multiple images are caused by the bending of the quasar's light as it passes near an intervening system of galaxies some 3 billion light-years from Earth.

As with most quests, Jason's journey was much more interesting than the reward at its end. "What became of the fleece afterwards," wrote the nineteenth-century American writer Thomas Bulfinch, in his classic *Mythology*, "we do not know, but perhaps it was found after all, like many other golden prizes, not worth the trouble it had cost to procure it."

Rest assured, though, that if a golden lens is found, it will retain its value. We astronomers will monitor its flickering year after year until it yields a firm, independent measurement of the Hubble constant. And we won't stop at one such lens; we'll study every golden lens we can find, to cross-check our results. The Argonauts' odyssey ended long ago, but this cosmological golden quest has only just begun.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

(Continued from page 63)

all believed that women get pregnant through certain spirit-laden foods.

Geopolitically, the Andamans seem an unlikely place for such an aboriginal stronghold. They lie smack in the middle of major trade routes that connect India, Singapore, and the Far East; native islanders must have long been accustomed to seeing sailing ships from the great mercantile empires pass within hailing distance.

Yet for centuries hailing was about all that happened—the islanders had a reputation for being fiercely hostile people who resembled African pygmies. Indeed, for two centuries the natives (the name "Andaman" has been linked with a Sanskrit word for "naked man") met most approaches by foreigners with arrows and stones. (That attitude was perhaps warranted by the fact that when ships did enter the island's precincts, they had a habit of abducting stray natives and selling them as slaves or curiosities.) With their dense jungles and fearsome population, the islands held little attraction for permanent settlements until 1858, when British colonists from India established a penal colony at a harbor on South Andaman, calling it Port Blair.

The arrival of Westerners led to the dissolution and demoralization that has befallen so many other groups of indigenous peoples: a once impenetrable society began to slowly come apart. The British brought unfamiliar diseases that drove one native tribe of Andamanese nearly to extinction by the end of the nineteenth century. Japanese invaders in the 1940s cleared swaths of island land for airstrips and military installations. An Indian government replaced the British after the war, and the islands became a prime target for development to accommodate the subcontinent's refugee population. By the 1970s the remaining members of the Onge tribespeople, living on the southernmost island, Little Andaman, had been forced into settlements after seeing their forests bulldozed so that authorities could resettle a flood of refugees from Bangladesh.

Madhusree Mukerjee, a former editor at *Scientific American*, has been coming to the islands since the mid-1990s to document the condition of the native population that remains: about 500 individuals of various tribes and dispositions. Many of them occupy a strange limbo between traditional and modern, living part-time in government housing but carrying on old ways whenever they can. Most Jarawa tribespeople still dwell in forested areas of the largest island, where they are openly hostile to settlement and to settlers. And then there are the Sentinelese, protected from any contact with the outside by government edict and by their isolated location, to the west of the island chain.

The story is a distressing one, and ironic in that the Indians, once British subjects, are now colonizers themselves. "We have to teach them some morals," the local secretary of tribal welfare tells Mukerjee, in a voice that echoes Queen Victoria's provincial governors. But the forces at work here are too impersonal and too relentless for either blame or hope. To be sure, the North Sentinelese are still more or less untouched, but one senses that they, too, will not remain that way for long. At the end of her tale, Mukerjee comes close enough to their island to see them, then retreats at the last minute as if she were carrying a contagion—as, in a way, she is. There's little she can do for the Andamanese, other than give us a glimpse of indigenous people still reeling from their first encounters with global civilization, seen through the eyes of one who wonders what it all means, both for them and for us.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

EXPLORER GUIDE

Arthur Ross Hall of Meteorites Reopens September 20

Interview with Curator Denton Ebel

Denton Ebel is curator of meteorites in the Museum's Division of Physical Sciences and curator of the reconceptualization and rebuilding of the Arthur Ross Hall of Meteorites, which reopens September 20, 2003. He spoke with us about meteorites, the new hall, and the likelihood of a meteorite falling near you.

R. MICKENS/AMNH

Denton Ebel holds the Johnstown meteorite which fell in Colorado in 1924. It is thought to be a piece of Vesta, one of the largest of the asteroids which orbit the Sun beyond Mars.

Q: What is a meteorite?

It's a rock from space. It's a piece of a shooting star that falls to Earth. It's a meteor when it's in the sky; when it hits the Earth it's a meteorite. Most meteorites are pieces of asteroids. A very few are comets.

Q: What do meteorites tell us?

Meteorites record the history of our solar system. When we look at disks where young stars are being formed today, the same processes are taking place that we think occurred when our Sun was born, 4½ billion years ago. But here we have the actual leftovers of that process so we can deduce how our solar system originated. If you could cool the Sun into a rock you could hold it in your hand, it would have the same chemical composition as some meteorites. Because it's a universal process, we are by extension learning about all the other solar systems out there and how they might form and, in particular, why is the Earth here, how do the elements necessary for life get distributed in a solar system among the planets, and then, of course, what makes some zones of the solar system habitable. Where might there be life? This is something that humans are interested in.

Q: What will be new in the Ross Hall of Meteorites?

Well, the architecture, for one thing, will be new. The ceiling will be raised to its full height, which gives you a sense of space since these are rocks from space. When you go into the halls of Gems and Minerals next door, you enter a cave-like kind of room, which is reminiscent of where those rocks come from.

When you enter the hall, you will be invited to ascend a 16-inch platform, which will exhibit the basic concepts. This is the introductory section. The raised platform will surround the central object, which is Ahnighito, the largest meteorite "in captivity," part of the Cape York meteorite. There is only one larger meteorite—in Africa, which is where it fell in Namibia—the Hoba meteorite. Two other pieces of the Cape York meteorite are also displayed in our new hall.

The hall surrounding Ahnighito has three sections addressing what meteorites tell us about the origins of our solar system, about the formation of the planets and planetary processes, and finally about how meteorites and the dynamic solar system interact with planets, particularly through impacts.

The Meteor Crater of Arizona will be highly featured in the hall with a scale model in a diorama. This is the best-preserved meteorite impact crater on the surface of the Earth, and it's 50,000 years old. It's in the Arizona desert so it's really very accessible, and we're collaborating with the people at the Meteor Crater Visitor's Center to create a really first-class model of it. It will have a cutaway section so you can see how the crater was originally shaped because it's got a lot of silt and infill in it—50,000 years is a long time.

Q: Can you describe how the hall will tie to some of the other Museum halls?

In the Museum there are several halls that deal with the physical sciences: the Cullman Hall of the Universe and the Gottesman Hall of Planet Earth in the Rose Center and the Morgan Memorial Hall of Gems and the Guggenheim Hall of Minerals. And the Ross Hall of Meteorites really fits between the Hall of the Universe and the Hall of Planet Earth. The universe is the setting in which our solar system formed. In the Hall of Meteorites, we focus on the origin of our solar system, the formation of planets, and the chemistry that underlies all of this, all through the meteorite specimens. This, in turn, provides the setting to explore the mysteries of planet Earth.

DAVID J. RODDY AND J.D. ZELLER/USGS

Meteor Crater, Arizona

Our hall is very different from an older school of meteorites display, which would look at meteorites with a classification or nomenclature kind of approach as simply rocks that have different properties. The new hall will be much more focused on the processes and what they tell us about the larger scenario. So it's more like a hall of meteorites and planetary origins, much in the same way that a hall of vertebrate evolution differs from a hall of fossils.

Q: Can you say a little about your own research?

My research has largely been in the chemistry of how the particular components of chondrites, very primitive meteorites, actually formed in the solar nebula. Chondrites are really sedimentary rocks made up of dust and then chondrules, these round droplets that were once molten and now are little beads, many containing glass, which were present in the early solar system.

I'm also working in collaboration with other scientists in looking at meteorites to see how they reflect and absorb light, like sunlight. Because one of the ways we understand the chemistry of, say, an asteroid is to look at all the wavelengths of light that it reflects from the Sun and then compare that to what we can measure in the laboratory on a known specimen. So if you have meteorites A, B, and C, you can measure what their spectra look like in ultraviolet or the infrared or visible light ranges. And then with our satellites and our spacecraft and our Earth-based telescopes we can do the same measurements of remote objects and we can say it looks like A or it looks like B or C. And in that way, if it looks like a duck, and it quacks like a duck...we can say to some degree what asteroids far away look like and what they might be.

Another cool thing that I've been doing is some work on tomography. This is CAT-scanning, three-dimensional imaging of meteorites, and is very new. We're just beginning to learn how to extract information this way. We intend to include a "fly-through" of a meteorite sample in a new production for the theater in the new hall.

Huckitta meteorite

Q: What are the real chances of a large-scale meteorite impact?

Well, we're not going to have a meteorite the size of Texas. First of all, anything that big we already have seen, we already know about. There's never in human history been an impact anywhere near the kind that wiped out so many of the dinosaurs. But here it's important to learn about the composition of asteroids that pass near Earth. If you have an object that is made of lots of smaller objects, like a pile of dust and stones, do you want to break it up or do you want to try to push it away?

If you jump into a swimming pool, it's no problem. If you jump off the George Washington Bridge, it's like hitting a brick wall. Same thing for meteorites flying through space at huge speeds. They hit the Earth's atmosphere and at first it just makes a lot of friction, but there's a thicker layer which we live in. We need to have oxygen to go to the top of Mt. Everest. Well, that's very high up. Around that height, a little higher actually, most meteorites hit this wall of air and they shatter or even vaporize. There are meteorites the size of your fist landing daily somewhere on Earth. But most meteorites land in the ocean, because it's by far the largest target.

The restoration of the Arthur Ross Hall of Meteorites is made possible through the generosity of the Arthur Ross Foundation.

CHRIS EBEL

MUSEUM EVENTS

EXHIBITIONS

D. FINNIN/AMNH

Porcelain statues of the spirit mandarins of the Mother Goddess religion

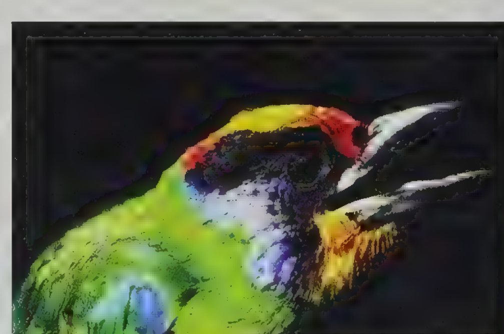
Vietnam:
Journeys of Body, Mind & Spirit
Through January 4, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

Experience the sights and sounds of a bustling

Vietnamese Marketplace

and sample traditional foods at Café Pho.
Through January 4, 2004
77TH STREET LOBBY, FIRST FLOOR



KEVIN FREY/AMNH-CBC

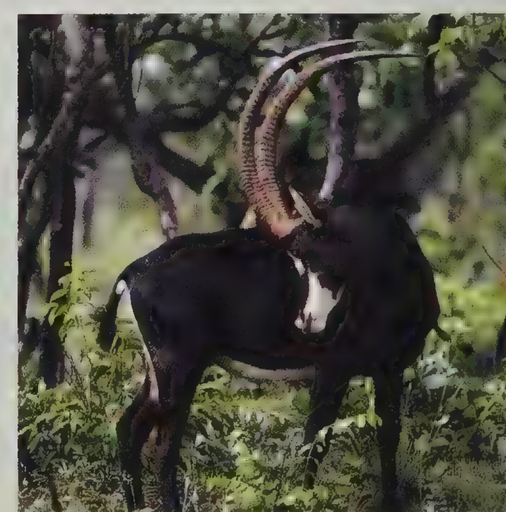
Golden-throated barbet, Ngoc Linh, Vietnam

Discovering Vietnam's Biodiversity
Through September 28
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

LECTURES

A Certain Curve of Horn
Tuesday, 9/16, 7:00 p.m.
John Frederick Walker weaves the fascinating story of the survival of the giant sable antelope, found only in Angola, with politics, colonialism, and revolution.



RICHARD D. ESTES

Sable antelope bull in the Luando Reserve, Angola

Prehistoric Art:
The Symbolic Journey
Thursday, 9/25, 7:00 p.m.
Anthropologist Randall White surveys the history of creative expression.

FIELD TRIPS

Fall Bird Walks in Central Park
Eight-week sessions start on September 2, 3 & 4.

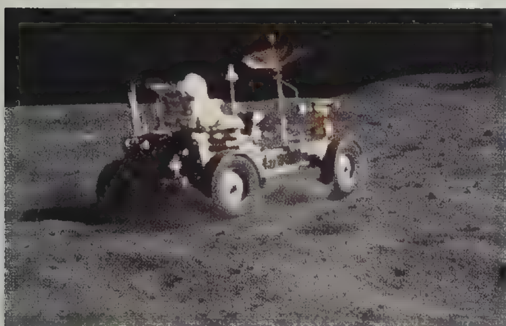
CHILDREN'S ASTRONOMY PROGRAMS

Stories of the Sky
Saturday, 9/20, 12:30–2:00 p.m.
(Ages 4–6, each child with one adult)

Einstein for Everyone:
Adventures in Light!
Sunday, 9/21, 12:30–2:00 p.m.
(Ages 4–6, each child with one adult)

I Want to Be an Astronaut
Tuesday, 9/23, 4:00–5:30 p.m.
(Ages 4–6, each child with one adult)

Fly Me to the Moon
Thursday, 9/25, 4:00–5:30 p.m.
(Ages 4–6, each child with one adult)


CHARLES M. DUKE, JR./NASA

Lunar Roving Vehicle

Space Explorers: The Planets (and Meteorites) of Our Solar System
Tuesday, 9/9, 4:30–5:45 p.m.
(Ages 10 and up) In the Hayden Planetarium Space Theater

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe:
Stellar Dynamics
Tuesday, 9/2, 6:30–7:30 p.m.
Redefine your sense of "home" on this monthly tour through charted space.

Celestial Highlights:
Stars of Autumn
Tuesday, 9/30, 6:30–7:30 p.m.
Find out what's up in the October sky.

Motion and Matter
14 Wednesdays, 9/3–12/10
College-level introduction to space science.


NASA

Choosing a Telescope
Three Mondays, 9/15–29
A practical introduction to the seemingly endless choice of telescopes available to the amateur astronomer.

Photons to Photos: Spying on Stars with Spectroscopy
Four Tuesdays, 9/23–10/14
This course addresses the methods astronomers use to deduce the history of stars and galaxies from the colors of the light they emit.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 5 and under)

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All programs are subject to change.


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Rose Center for Earth and Space

Ray Baretto and His Band

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Private Choices

By Dru Clarke

The kick screen was weighed down with a slime of wet, fallen leaves and hairy algae. The children hauled it from the creek bed onto a level place along the bank. There they eagerly knelt beside it and, with forceps, began to grasp anything that moved, transferring their finds to white plastic ice-cube trays filled with creek water. The fourth-graders, from the town of Saint George in northeastern Kansas, were taking part in a project called Streamshot, and our purpose was to measure the environmental health of Blackjack Creek. Our assessment would be simply an index of its macroinvertebrates, a sampling of small but not microscopic animals widely used as indicators of freshwater quality.

The children's trays began to fill with mayfly nymphs, aquatic sow bugs, and the larvae of blackflies, caddis flies, and bloodred midges. And clinging to the slippery underside of the very last leaf was a leech. Teased from its tenuous hold, the leech slid into one of the tray's compartments and immediately sensed a change in its surroundings. Suctioning itself to the bottom of the tray, it accordioned its way around the confines of the strange white room, then reared up like a rising periscope to take a look around.

The kids shrieked with joy, awe, and horror. "Watch out! It'll suck your blood!"

I assured them that this was a vegetarian leech.

"How do you know?"

"Well, it was on a leaf, wasn't it?"

Finally they calmed down to watch its sinuous movements with fascination.

I usually released our captured "macros" at the end of our surveys, but on that day I had agreed to preserve them as specimens for the school's reference collection. Sometimes we have to make tough choices. I dumped the contents of the ice-cube trays into a jar and screwed on the lid.

Later that afternoon I deposited the jar in the refrigerator of the education department office. But the fridge wasn't working properly, and when I returned to retrieve the jar several days later, the water—and everything in it—was frozen solid. I thrust it quickly into a nearby microwave oven, then began delicately separating the lifeless invertebrates and tweezing them into individual specimen jars filled with alcohol and water.

Suddenly a gliding movement in the bottom of the collection jar caught my eye. The leech was alive! Somehow the creature had survived the freezing and thawing unscathed. I dumped the contents of the jar into a pie pan, and there the leech continued its exploratory behavior, alternately squeeze-boxing its finely segmented body into a tight ball and expanding to a full inch and a half.

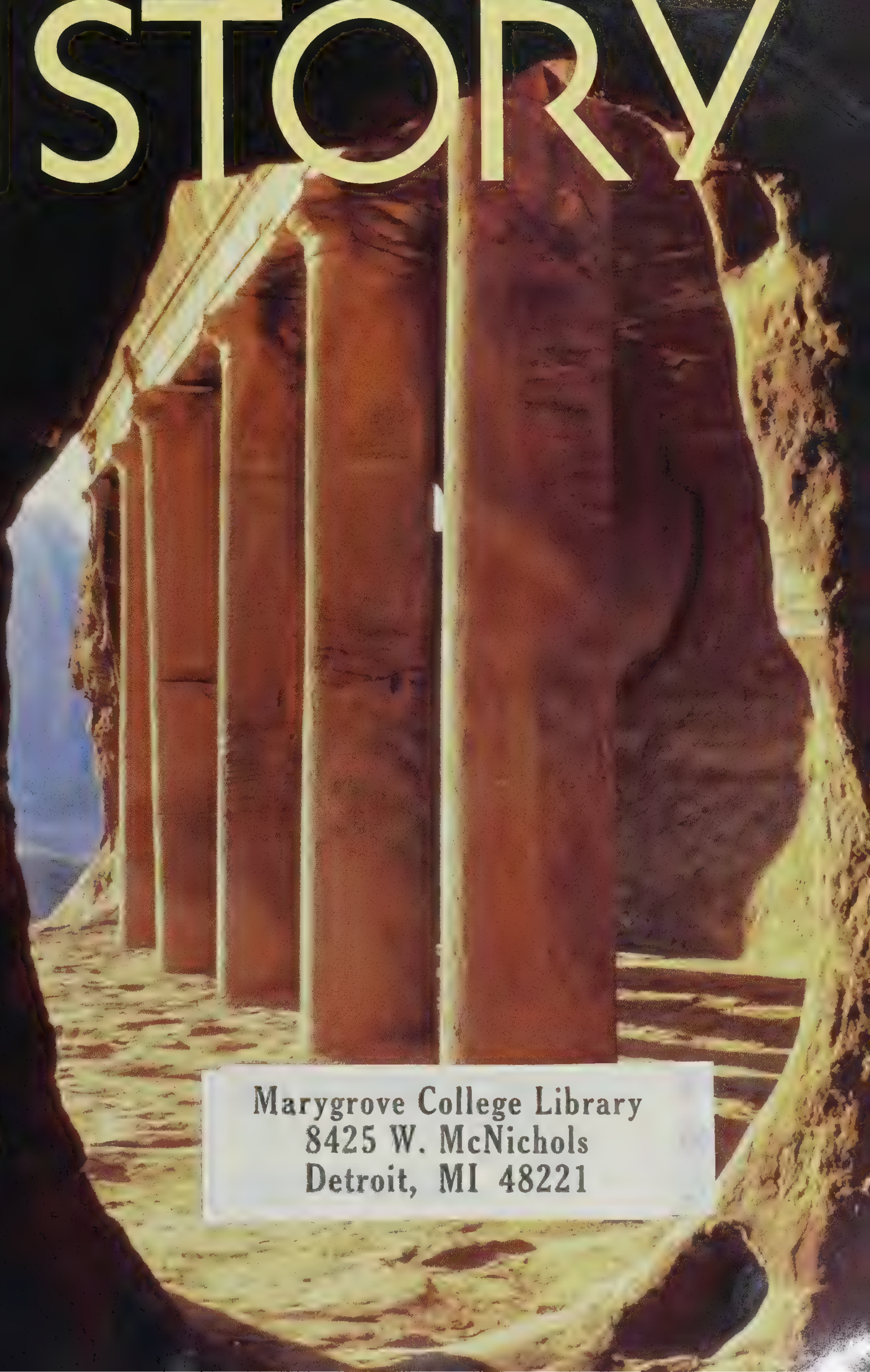
I was amazed and humbled by its grit. I put the animal in my palm and felt a slightly pleasant sensation as it crept along my "life line." Its personal specimen jar was labeled and waiting. I hesitated, then dumped the alcohol mixture from the specimen jar, rinsed it, and filled it with the thawed creek water. I tweezed the now frantically squirming leech into the container, put it into a shoebox with the rest of the collection, and headed for home.

After dinner I peeked into the shoebox: the leech had climbed to the top of its jar and was huddled inside the lid. "Enough of this," I thought. Shoving the jar into my coat pocket, I rummaged for my car keys and drove to the banks of Blackjack Creek, parking at the spot where we had collected our samples. After tossing the jar's contents into the dark water, I watched the flowing creek in the beams of my headlights for a few more minutes. Nothing stirred on the surface. The leech was home free. Sometimes our choices become epiphanies.

Dru Clarke taught marine science and ecology in secondary school for thirty-one years. She lives in the Flint Hills of northeastern Kansas.

NATURAL HISTORY

10/03



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Antarctica

Penguin fossil expert Julia Clarke leads this extraordinary expedition to the Antarctic Peninsula aboard the new ship *Orion.* Via ship and Zodiac boats, you'll visit busy penguin rookeries, encounter whales and seals, and witness an ever-changing panorama of tabular icebergs and snowcapped mountains.

January 29 - February 11, 2004
Study Leader: Julia Clarke,
American Museum of Natural History

Antarctica, South Georgia, and the Falklands

Explore the natural and geological wonders of Antarctica with geologist Malcolm McKenna and Trevor Potts, an expert on Polar explorer Ernest Shackleton. In addition to Antarctica you'll visit Elephant Island, where Shackleton's crew took refuge; the remote Falkland Islands; and spectacular South Georgia.

February 18 - March 11, 2004
Study Leader: Malcolm McKenna,
American Museum of Natural History emeritus

The Mighty Amazon

Join ornithologists Francois Vuilleumier and Paul Sweet on an extraordinary 2,000-mile journey along this storied river. Via ship and Zodiac boats, you'll venture into a labyrinth of narrow tributaries, trek through the rain forest, and visit isolated river villages, everywhere encountering the region's remarkable wildlife.

March 30 - April 17, 2004
April 15 - May 2, 2004
Study Leaders: Francois Vuilleumier & Paul Sweet, American Museum of Natural History

Sicily: Crossroads of Mediterranean Civilizations

With its treasures from throughout the ages, Sicily is a virtual living museum. On this unique circumnavigation you'll see some of the most important remains from the Greek, Roman, Byzantine, and Renaissance periods.

June 1 - 11, 2004
Study Leader: TBA

The Circumnavigation of Newfoundland

Naturalists Alan and M.J. Brush team up with whale expert Pierre Beland on this in-depth exploration of Newfoundland. Excursions include Witless Bay Ecological Reserve; Terra Nova National Park; Twillingate Island; Gros Morne National Park; and the ancient Viking settlement at L'Anse Aux Meadows.

June 11 - 19, 2004
Study Leaders: Alan and M.J. Brush, American Museum of Natural History, and Pierre Beland, St. Lawrence National Institute of Ecotoxicology

Treasures of the Adriatic Sea

Discover the extraordinary art and architecture that can be found in the string of unspoiled cities lining the Adriatic. The itinerary includes Venice, Split, Mostar, Dubrovnik, Kotor, Ravenna, and the unusual hilltop Trulli villages.

June 26 - July 6, 2004
Study Leader: Anne-Marie Bouché,
Princeton University

The Great Lakes

Discover all five of the Great Lakes on this fascinating journey through the American heartland. Highlights include the scenic Thousand Islands of Lake Ontario, Whitefish Point Bird Observatory, beautiful Mackinac Island, Niagara Falls, and a traditional Native American powwow.

July 17 - 25, 2004
Study Leader: Al Duba,
American Museum of Natural History

Greenland and the Canadian Arctic

Experience the abundant wildlife and the captivating landscapes of the Far North on this study voyage along the rugged coasts of Greenland and northern Canada. You'll also witness the fascinating art and culture of the native Inuit people.

July 24 - August 6, 2004
Study Leader: Francois Vuilleumier,
American Museum of Natural History
August 20 - September 2, 2004
Study Leader: Robert Rockwell,
American Museum of Natural History

Journey of Odysseus

Journey into the realm of gods, nymphs, and monsters on this voyage that traces the epic travels of Odysseus. Excursions include Troy, where Odysseus' journey began; Mycenae, the kingdom of Agamemnon; Malta, home of Calypso; Sicily; and Ithaca, the hero's long-sought home.

October 7 - 21, 2004
Study Leader: Daniel Mendelsohn,
Princeton University

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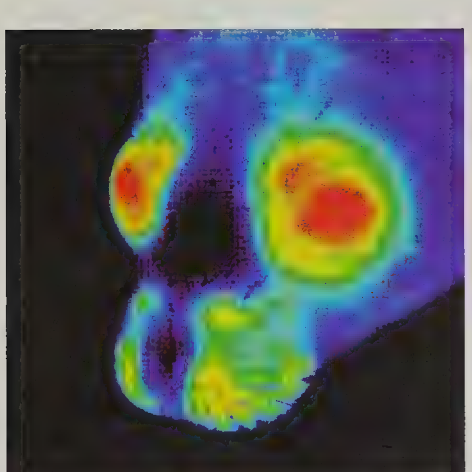
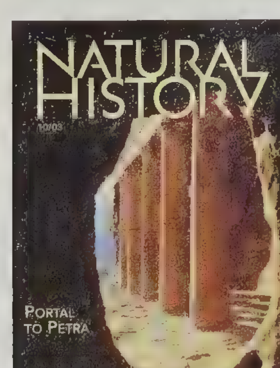
NATURAL HISTORY

OCTOBER 2003 VOLUME 112 NUMBER 9

FEATURES





COVER
Petra: View from within the Urn Tomb.

STORY BEGINS ON PAGE 40

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DEPARTMENTS


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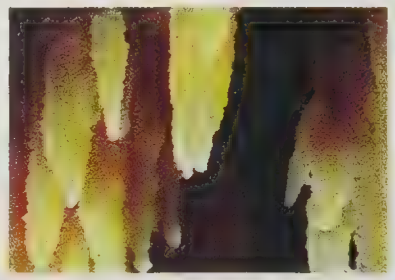
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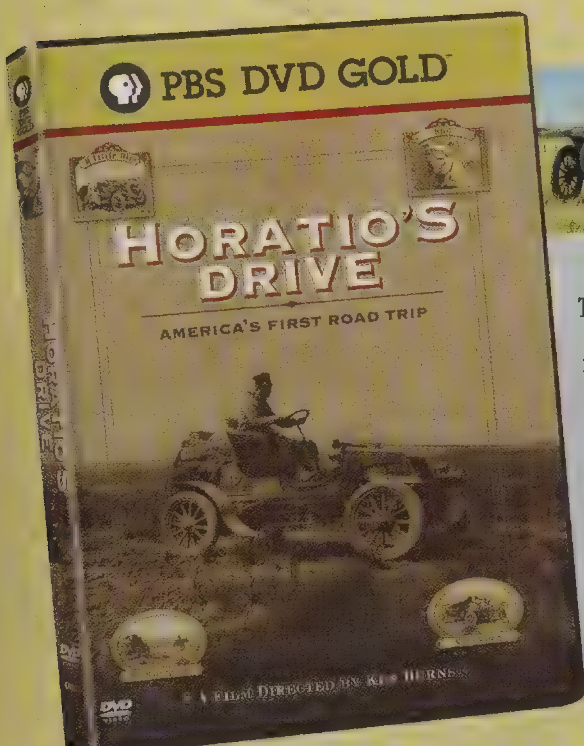
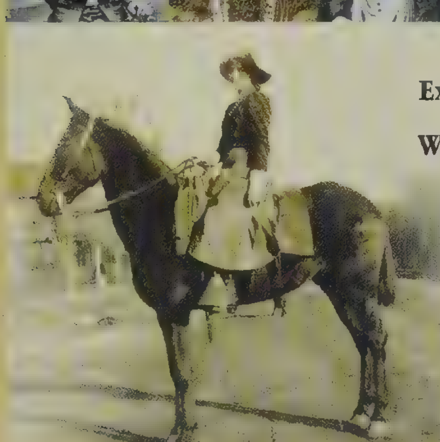
PICTURE CREDITS: Page 10

MASTER STORYTELLER KEN BURNS
takes you on a journey across America.

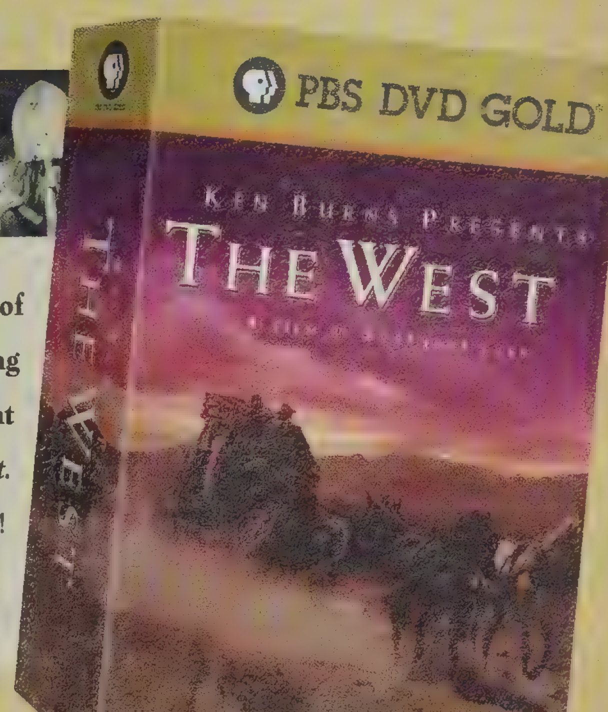
Acclaimed filmmaker Ken Burns presents his newest film, the lighthearted HORATIO'S DRIVE, produced with Dayton Duncan, and his masterpiece THE WEST, produced with Stephen Ives, now on DVD.



Tom Hanks is the voice of America's first road tripper, Horatio Nelson Jackson, in *Horatio's Drive*... an adventurous and sometimes hilarious tale that's bound to fuel your imagination! New to DVD and videocassette.



Experience both the exhilarating triumph of Western expansion and the heart-wrenching tragedy of Native American displacement in the 9-part series *The West*. Now for the first time on DVD!



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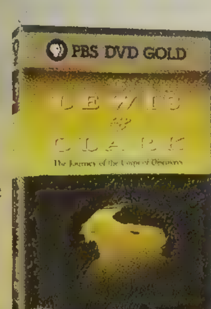

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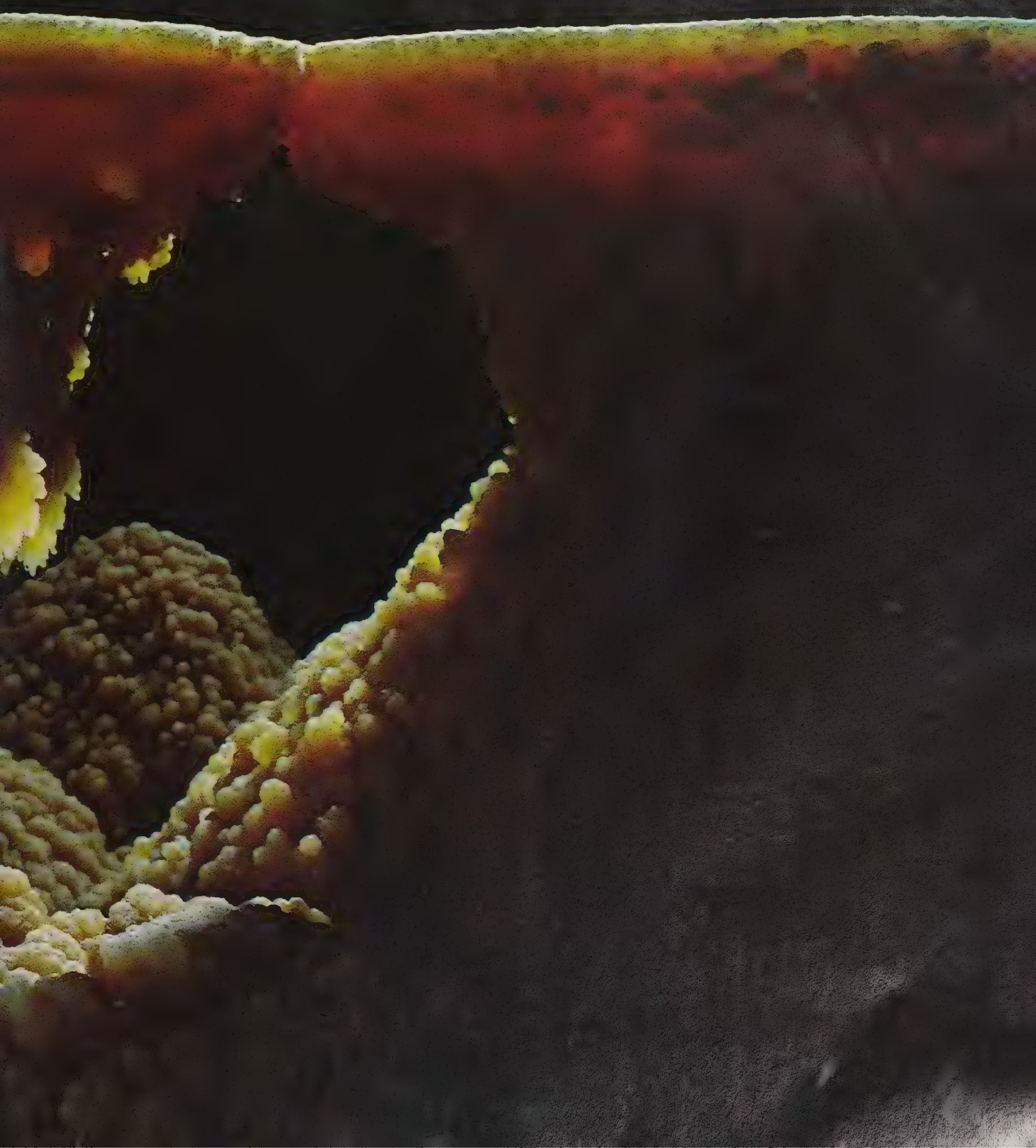
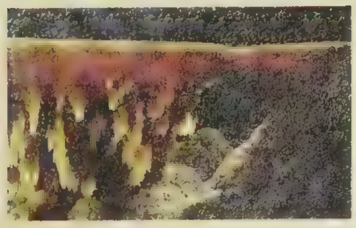
What Life Looks Like on Mars?

Photograph by Dave E. Bunnell



See preceding pages



A week of tramping for miles underground and sleeping in limestone catacombs tunneled out by sulfuric acid is not everyone's idea of happy camping. But Dave E. Bunnell—photographer and cave aficionado—is not everyone. He was thrilled to be among a small party of cavers allowed to map an arm of Lechuguilla Cave in southern New Mexico, the deepest cave in the continental United States. A few days in, after dozens of "squeezes" and lengthy rope climbs, Bunnell and his team stumbled across the area of orange calcite growths in the photograph, measuring several feet across.

This stunning cave is populated by a spectacular array of microorganisms. For despite the lack of light and nutrients, bacteria have adapted to Lechuguilla, some by absorbing metals such as manganese and iron. A number of investigators, among them Leslie Melim of Western Illinois University in Macomb and Diana Northup of the University of New Mexico in Albuquerque, are studying how the bacteria can build up calcified assemblages in caves—adding to the decor.

Melim and Northup believe that bacteria may have helped form the icicle-like extensions, known as "pool fingers," which point downward in Bunnell's picture. "Our working model is that bacterial slime is replaced or coated by calcite," says Melim. Such work in "extreme" environments is helping redefine where biologists search for life or its remains: think extraterrestrial.

—*Erin M. Espelie*

Desert Secrets

It is impossible to conceive any thing more aweful or sublime than such an approach [to the ancient city]: the width [of the desert canyon] is not more than just sufficient for the passage of two horsemen abreast; the sides are in all parts perpendicular, varying from 400 to 700 feet in height; . . . and there is little more light than in a cavern. . . . We followed this half subterranean passage for the space of nearly two miles, the sides increasing in height as the path continually descended.

—Charles Leonard Irby and James Mangles, *Travels in Egypt and Nubia, Syria and the Holy Land* (London, 1868), quoted in *Petra: A Travellers' Guide,* by Rosalyn Maqsood

Once, 2,300 years ago, the ghost town at the end of the path—which you can still visit along the passage dramatically described above—was a bustling metropolis carved into the sandstone cliffs, its Broadway already excavated by a long-vanished stream. Petra, in what is now southern Jordan, was the Washington and New York City of the Nabataeans, the capital city and cultural center of a powerful nation built on the spice trade. When Steven Spielberg sought locations for his movie *Indiana Jones and the Last Crusade,* Petra was the site that shouted, "hidden treasure in the desert."

On October 18 a new exhibition, "Petra: Lost City of Stone," opens at the American Museum of Natural History in New York City. Some 200 objects will be on display through July 6, 2004. The exhibition then moves to the Cincinnati Art Museum, the co-organizer of the show, and thereafter to several other venues. "Portal to Petra," our gallery of pictures with text and captions by longtime Petra scholar Martha Sharp Joukowsky, begins on page 40.

• • •

Tectonic forces uplifted the sandstone in which Petra was carved, and those same forces created the deep, flattened depression, immediately to the west, known as the Dead Sea valley. Now investigators from a broad range of disciplines have made it clear that those geological events directly affected the course of human history. Between 2 million and 3 million years ago tectonic-plate movements opened a corridor linking northeastern Africa with the Near East. In those days, as Zvi Ben-Avraham and Susan Hough tell the story in "Promised Land" (page 44), the climate was much milder and wetter than it is today—so gentle and inviting, in fact, that it lured a rich flora and fauna, including early humans, out of Africa along the new land route. Stone tools discovered in the corridor, bearing a striking resemblance to tools unearthed in Africa, have been dated to 1.4 million years ago—a date that makes Petra's heyday seem as recent as yesterday's newspaper.

—PETER BROWN

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1996, caver and photographer **DAVE E. BUNNELL** ("The Natural Moment," page 6) has been the editor of *NSS News*, the magazine of the National Speleological Society. His photograph of orange flowstone was made in the western branch of Lechuguilla Cave, near Carlsbad Caverns in New Mexico, during a mapping expedition at the site (see his Web site at www.goodearthgraphics.com/virtcave).

MARTHA SHARP JOUKOWSKY ("Portal to Petra," page 40) is a professor with a dual appointment at Brown University in Providence, Rhode Island: at the Center for Old World Archaeology and Art and in the department of anthropology. Since 1992 she has served as the director of the Brown University Petra Great Temple Excavations. She is the author of six books and more than fifty scholarly articles, and has served as president of the Archaeological Institute of America.

For the past twenty-five years geophysicist **ZVI BEN-AVRAHAM** ("Promised Land," page 44) has been investigating the geologic and cultural history of the fault zone around the world's lowest, saltiest lake, the Dead Sea. He is director of the Minerva Dead Sea Research Center at Tel Aviv University in Israel and a professor of marine geoscience at the University of Cape Town in South Africa. Ben-Avraham is the author or editor of more than 150 scientific papers, as well as eight monographs and books. **SUSAN HOUGH,** a seismologist with the U.S. Geological Survey in Pasadena, California, focuses her research on faults and earthquakes elsewhere in the world. Her article, written with Roger Bilham, on the earthquake zone in western India ("Shaken to the Core") appeared in the February 2003 issue of *Natural History.*

TERRIE M. WILLIAMS ("Sunbathing Seals of Antarctica," page 50) is a professor of biology at the University of California, Santa Cruz. In California she competes as a triathlete, but each year from September to December she trades in her running shoes, wetsuit, and bicycle for parka, insulated boots, and snowmobile to study Weddell seals in the Antarctic. *The Hunter's Breath,* a book for nonspecialists about her team's Antarctic exploits and their research into the icy life of Weddell seals, will be published early in 2004 by M. Evans and Co., Inc.

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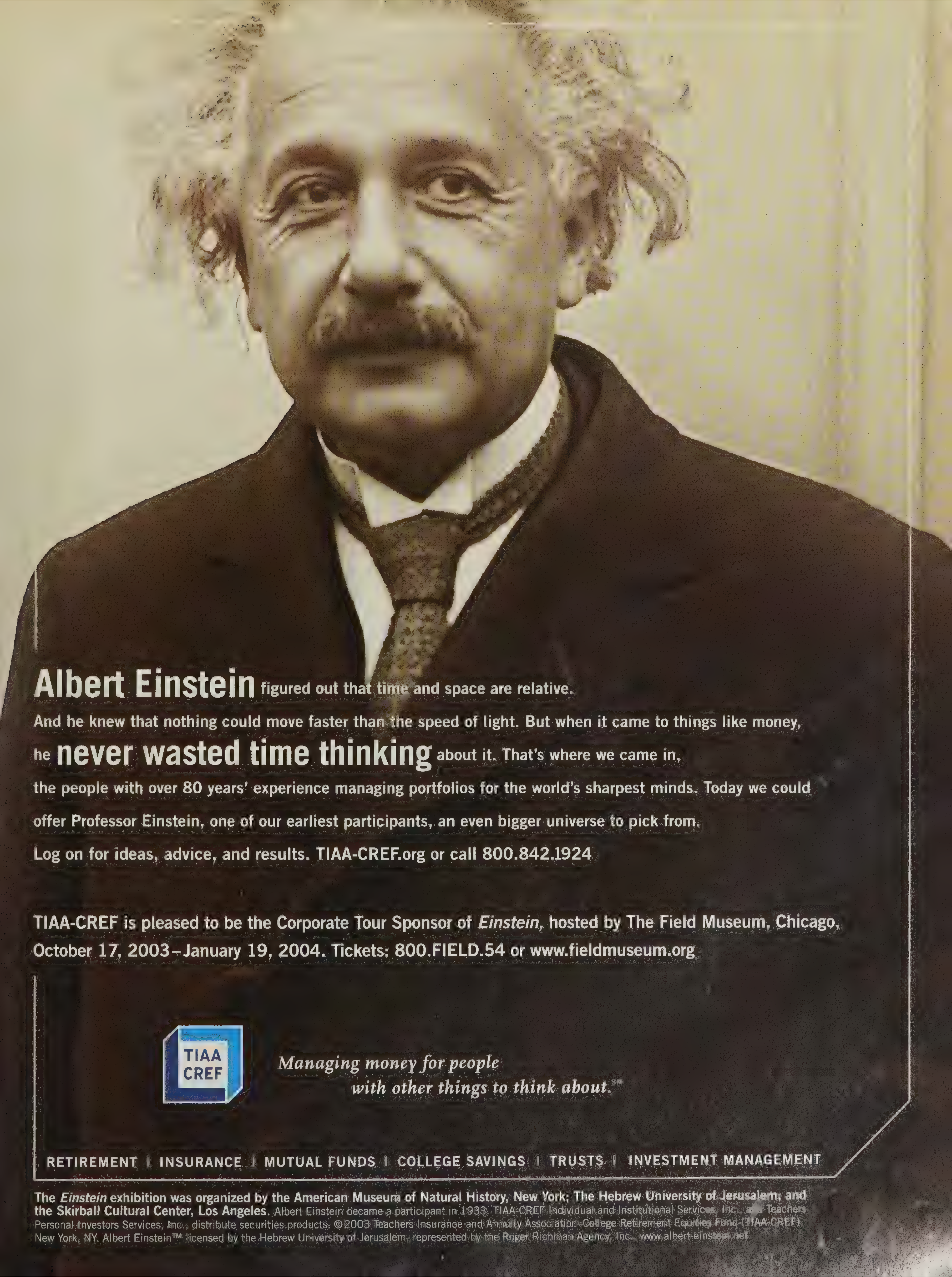

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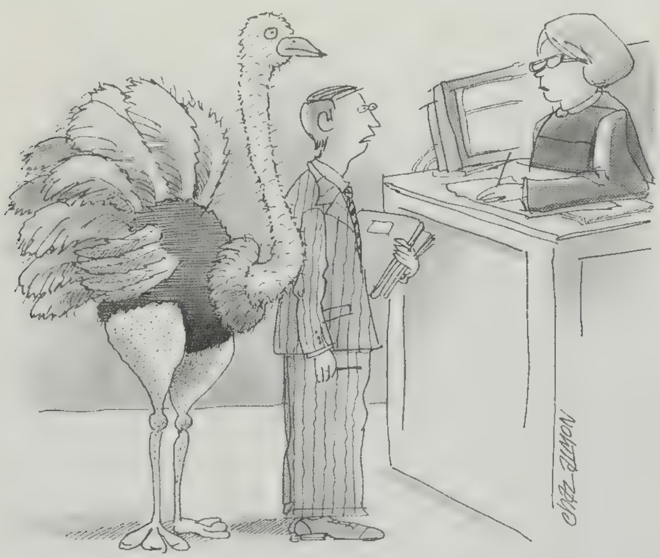
War of Words about War

R. Brian Ferguson ("The Birth of War," 7/03–8/03) has long believed the past was peaceful and has steadfastly ignored the archaeology refuting that myth. What he fails to realize is that most archaeologists have also fallen prey to the same myth and that, consequently, the research he relies on itself misreads the past as sublimely peaceful. Although he is now willing to see some warfare in the past—essentially only in the past 10,000 years—Mr. Ferguson continues to believe the myth that people have lived in ecological balance throughout most of human history, and as a result uses outdated interpretations in an attempt to salvage his own politically correct interpretations.

Why people engage in warfare is an important topic, and archaeology and ethnology provide essential information about it. Public policy derives ultimately from what we collectively think about this issue. Readers of *Natural History* who want to be usefully informed about the causes and history of warfare should also read newly formulated sources, such as Lawrence Keeley's book *War Before Civilization* and my own *Constant Battles: The Myth of the Peaceful, Noble Savage.*

My goal in my book *Constant Battles* was to synthesize the considerable body of information on past warfare and ecology.



"We request low bail, Your Honor. My client is no flight risk."

The evidence is overwhelming that warfare and ecological balance have been linked for millennia. Warfare in the past is patterned and explainable. Most important, warfare was just as intense and deadly in the deep past as it was in the more recent past.

Steven A. LeBlanc
Peabody Museum of Archaeology and Ethnology
Harvard University
Cambridge, Massachusetts

R. Brian Ferguson discusses prehistoric evidence as poorly as one might expect from a non-archaeologist. His omissions and errors are too numerous for this brief response—almost every generalization he makes about when and why warfare began is contradicted by archaeological facts.

Let one example suffice, the assertion that warfare began when people settled down and began farming. Wrong. The Natufians of the Near East, still as foragers, were the first people in the world to live in permanent villages—stone-walled houses, house mice, and so on. Yet they were quite peaceful, at least compared with recent tribal people. The equally sedentary Pre-Pottery Neolithic people who followed were the world's first farmers, and they, too, were peaceful. Meanwhile, their contemporaries, the mobile foragers of the Nile Valley, were very violent. Similarly, in the American Midwest, war deaths were common among Late Archaic foragers (3800–1500 B.C.); rare during the later semi-agricultural, sedentary Middle Woodland period (1500 B.C.–A.D. 900); and became common again among the later Mississippian farmers (900–1450).

Note too that during the three-day Civil War battle of Gettysburg, only 3 or 4 percent of those actively engaged were killed. Thus, many of the "peaceful" prehistoric people Mr. Ferguson mentions lived in circumstances, in many cases lasting for generations, that were as murderous, or more murderous, than one of the bloodiest modern battles.

As for the difference between human capabilities and what people actually do, all humans are capable of understanding archaeology, logic, and arithmetic. But, just as with making war, not all of them do so all of the time.

Lawrence H. Keeley
University of Illinois at Chicago

I suggest that the underlying motive for conflict is internal to societies and cultures, not external. War and the preparation for war enables people with certain abilities to acquire greater power and more resources, not primarily from their enemies, but in relation to others within their own society.

Suppose I am an engineer skilled at building walls. Because I will do well in times of war, my behavior will subtly favor a culture of war, thereby gaining me higher standing in my society and a larger share of its wealth. True, if there are warlike people in a nearby group, we ourselves must be warlike. But in a sense, those who stand to benefit from conflict within each group are partners in maintaining the dynamic.

Alan Silverman
Stone Ridge, New York

R. Brian Ferguson suggests that the scarcity of evidence is particularly telling in the case of prehistoric warfare. Yet I am sure that a survey of burials in the United States in the twentieth century would show that the vast majority of skeletal remains show no evidence of battle injuries, even though the U.S. has been at war for twenty-two out of the past

hundred years and has been involved in militarized disputes off and on during most of the years of so-called peace. Indeed, most burials in U.S. military cemeteries in recent decades would indicate a death by natural causes. Fatalities in warfare are rare, even in an era when warfare is ubiquitous. If warfare is intended to test relative capability and resolve, and if prehistoric combat managed to do so with few casualties, then warfare could have been more common than the archaeological evidence suggests.

Mr. Ferguson writes that "the decision to wage war involves the pursuit of practical self-interest by those who actually make the decision." It is not clear how this observation squares with his argument that war is an innovation of human prehistory. If war is relatively recent, so too must be its causes. But surely the pursuit of practical self-interest is not a recent human innovation. In any case, wars are episodic, with beginnings and ends. Like a light switch, a cause of war must be switched on and then switched off as the conflict proceeds. Yet if wars are precipitated by ethnic hatred, scarcity, or the fact that leaders gain from them, it is unclear how they can end—unless we are also prepared to believe that Serbs stopped fighting Muslims because they stopped hating, that peace came to East Timor because Indonesia became richer in the late 1990s, or that the first Bush Administration's desire to gain political power from the Gulf War was satisfied only a hundred hours after the land invasion began.

One remarkable finding about warfare, now widely accepted by students of international relations, is that states with liberal political systems—democracies—are much less likely than are other political systems to engage each other through combat. If the first inklings of civilization led to warfare, it may be, paradoxically, that the most sophisticated political structures yet developed can offer the promise of less war in the future. This rumination is germane both to the cradle of civilization, and to warfare: in the contemporary Middle East, democracy is in short supply.

Erik Gartzke
Columbia University
New York City

R. Brian Ferguson cites a finding by the anthropologist Raymond C. Kelly that hunter-gatherers whose social organization only loosely extends beyond family are warless, whereas war is more common among those with larger and more defined groupings, such as clans. But simple numbers might explain that difference better than type of social organization. Larger numbers increase the chances that a grievance could spark a conflict, and that the conflict would involve group violence rather than, say, murder. Furthermore, the smaller the group, the less able it is to tolerate the loss of multiple individuals.

Ken Morgan
Williston Park, New York

My heartfelt thanks to R. Brian Ferguson for three sentences that express clearly why I have so much trouble believing the rhetoric that relentlessly bombards us: (1) "My view is that in most cases . . . the decision to wage war involves the pursuit of practical self-interest by those who actually make the decision." (2) "Those advocating war always define it in terms of the highest applicable values." And (3)

[illegible] art wars usu- [illegible] believe in the [illegible]ousness of their chosen course."

I agree emphatically, but unhappily, that our skill at rationalizing our choices confirms his ending statement: "It is that capability that makes human beings such a dangerous species."
LaVerne C. McGee
Anderson, South Carolina

R. BRIAN FERGUSON REPLIES: In spite of Steven A. LeBlanc's suggestion to the contrary, I have often written about prehistoric warfare. As early as twenty years ago I argued that the Pacific Northwest Coast potlatch was, in part, a response to a pattern of deadly warfare, which I asserted went back at least 3,000 years. For another instance, in a 1992 article in *Scientific American* I wrote: "Even in the absence of any state, archaeology provides unmistakable evidence of war among sedentary village peoples, sometimes going back thousands of years."

Nothing I have ever written suggests that prehistoric people lived in some Eden-like idyll of natural conservation, the myth that Mr. LeBlanc attacks. He appears to think that is the only alternative to warfare over food resources. But a variety of other processes—crashes in the food supply, low life expectancy, high infant mortality, migration—keep populations from overwhelming their available resources. Isn't that the way of life on Earth? I am hardly against ecological explanations of war, having offered a few myself. But having "been there, done that" with ecological anthropologists more than a dozen years ago, I am aware of the limitations of these kinds of explanations.

By all means, interested readers should read *War Before Civilization* and *Constant Battles.* When they do, they should keep a sharp eye out for how often the authors attack a position without providing any specific citation showing that someone has actually taken that position. Readers would also do well to note how few archaeological cases (as opposed to ethnographic cases) the authors actually describe in support of their sweeping conclusions about the prehistoric record. Even Mr. LeBlanc's crucial discussion of the European site Dolni Vestonice, I am prepared to argue, bears almost no resemblance to the actual findings there.

Where tribal warfare exists, combat may account for more than 25 percent of adult male deaths.

Lawrence H. Keeley maintains that just about everything I say is wrong, but the one example he bothers to cite is itself misguided: that I claim there was no war before people "settled down and began farming." I make no such claim. Agriculture is associated with a variety of developments that, over time, make war more likely, but it is neither necessary nor sufficient for war to develop. My article specifically discusses pre-agricultural people who made war and agriculturalists who did not. Some of the details Mr. Keeley mentions, such as the sequences in Eastern North America, I could not include because space was limited. While we're at it, the violent, at least partly sedentary foragers of the Nile Valley (Site 117, in Sudan, in my article) were not contemporary with the Pre-Pottery Neolithic people, but lived 2,000 to 4,000 years earlier.

I agree with Alan Silverman that motives for conflict should be sought within war-making societies, but not to the exclusion of external incentives.

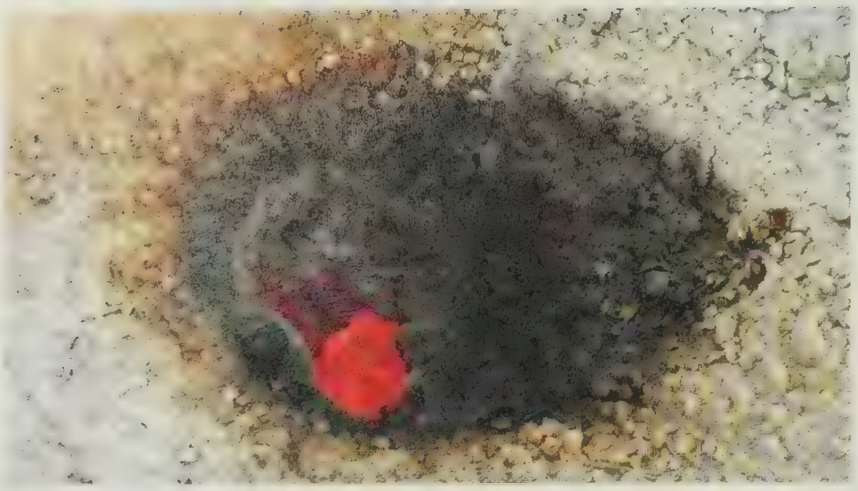
Erik Gartzke raises several interesting points. On the paucity of skeletal trauma, one cannot compare tribal war to modern war without qualifications. Here I am in line with Mr. Keeley in *War Before Civilization.* In tribal combat, mobilization can exceed 40 percent of adult males, battles that are mere tests of resolve rather than an effort to kill are rare, and combat death not infrequently accounts for more than 25 percent of adult male deaths. Imagine our graveyard populations if such figures applied to us.

Yes, I believe humans have always pursued practical self-interest. But the conditions that make self-interest lead to war became common only in the past 10,000 years. I do not see war as switched off and on like a light. I agree that how wars end needs much more study, but I doubt that many of them end because the conditions that started them are somehow reversed. I also am interested, even encouraged, by findings in the literature on "democratic peace." More democracy may put a brake on the unbridled power of leaders—though as the past year shows, not always. But that issue was far beyond my topic.

I agree with Ken Morgan that numbers are important. As for Raymond C. Kelly's findings, which Mr. Morgan mentions, I would note that Kelly does not address what makes formal groupings such as clans and lineages emerge. There is a good deal of support for the idea that among the forces behind the emergence of clans are growing populations and the consequent competition for resources. It could be, as Mr. Morgan suggests, that small hunting bands place a higher value on individual lives, making war seem less of an option. Some investigators have also stressed that for small, scattered groups of big-game hunters, the logic of self-interest works against territorial conflict and encourages ramifying networks of information exchange and movement.

Natural History's e-mail address is nhmag@naturalhistorymag.com

By Stéphan Reebs



Burning ground in northern Mali

Hot Rocks

For centuries the nomadic Tuaregs of the Sahara, warned off by legends of diabolical fumes and flames, have avoided camping in the dry lake beds around Timbuktu, Mali. Some geologists noted similarities between the lakes' steaming cracks and the fumaroles of volcano craters—and wondered if magma might be brewing there. Problem was, West Africa has no active volcanoes and is tectonically stable. Henrik Svensen, a geologist at the University of Oslo in Norway, and several colleagues went to investigate.

The team took a direct approach: they dug an eight-foot-deep trench into the leading edge of a smoking, migrating heat front. What they found wasn't fiery lava but a layer of smoldering peat—the result of microbial decomposition of the organic residue left in the sediment when a lake has dried out. The decomposition generates so much heat that the buried peat self-ignites, roasting the ground above it to temperatures as high as 1,400 degrees Fahrenheit. ("Subsurface combustion in Mali: Refutation of the active volcanism hypothesis in West Africa," *Geology* **31**:581–84, July 2003)

Reading the Leaves

When soil is poor in phosphorus, plants put a lot more effort into growing hairy roots than they do into growing the parts people eat. So, to make sure crop yields are high, farmers tend to use a lot of fertilizer. But excess phosphorus leaches out and eventually triggers blooms of algae that choke lakes and rivers; besides, cheap natural sources of phosphorus will be exhausted in less than a century. Wouldn't it be great if a farmer could know, just by looking at a plant, when it needs a hit of the stuff?

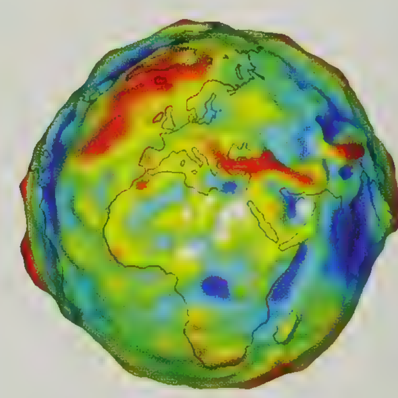
Biotechnology to the rescue. John P. Hammond of Horticulture Research International in Warwickshire, England, and his colleagues have pointed out that a gene known as *SQD1* could play a role in such signaling. *SQD1* gets activated when plants are starved of phosphorus but not when they're stressed by other problems. Moreover, that response takes place before the plant's growth has been compromised by a decline in phosphorus.

By welding *SQD1* to another gene—one that makes a substance visible in leaves—Hammond and his team have created a plant that signals its own needs. By checking its leaves regularly, a farmer could see at once whether the plant is hungry for phosphorus. ("Changes in gene expression in *Arabidopsis* shoots during phosphate starvation and the potential for developing smart plants," *Plant Physiology* **132**:578–96, June 2003)

Serious Gravity

If the Earth were a uniform orb both inside and out, its gravity—and thus your weight—would be the same everywhere. But our planet is flattened at the Poles; it has deep seafloor trenches and towering mountain ranges; the density of the rock underfoot is far from uniform; and gradual processes such as the melting of polar ice and the flow of rock in the mantle redistribute its mass. That makes Earth's gravity field vary from place to place (and even from time to time): you'd weigh slightly more in Tokyo than you do in Tulsa.

A joint five-year U.S.-German space mission—the Gravity Recovery and Climate Experiment (GRACE)—is now bringing unprecedented precision to the measurement and mapping of Earth's gravity field. Since March 2002, two identical satellites have been following the same orbit around the globe, some 130 miles apart, and when they encounter minute variations in the strength of the gravity, the distance between them fluctuates. Because that fluctuation can be measured to within a tenth of a hair's breadth, geophysicists at NASA and the German Aerospace Center in Potsdam can now map changes in gravity with exquisite accuracy.



Model shows how gravity varies slightly around the Earth. Blue "valleys" represent relatively weak gravity fields, and red "peaks" relatively strong ones. The valleys and peaks are exaggerated for clarity.

Why should anyone trouble to measure the global gravity field? The average field ultimately reveals a lot about ocean circulation and the structure of the seafloor; the fluctuations provide early signs of shifts in weather patterns and long-term climate change. (www.csr.utexas.edu/grace)

Experiment of the Month

Question: How did the dung beetle cross the road? Answer: By moonlight.

This past March this column noted the first-ever evidence of an animal—the elephant hawkmoth—seeing color by night. Now another insect has joined the ranks of the perceptually advantaged.

When a dung beetle finds a pile of fresh manure, it selects the choicest, least-fibrous bits and crafts them into a large ball that will supply its own dinner for days to come or serve as both shelter and food for its developing young. Rolling the ball away from the raw dung heap as quickly and efficiently as it can (so that the ball won't be stolen and the work wasted), the nocturnal beetle heads off in a straight line—if the Moon is out. On moonless nights, though, it zigzags all over the place.

African dung beetle (Scarabaeus zambesianus) *rolls its dinner home.*

Orienting itself by the direct light of the Moon would not win the dung beetle any space here; many other animals do that. But when Marie Dacke, a biologist at Lund University in Sweden, and several colleagues shielded the rising Moon from the beetles' direct view, the insects still moved in a straight line. Could the beetles have been navigating by polarized moonlight—extremely feeble illumination that is scattered by minute particles in the atmosphere—rather than by the Moon itself?

To test the idea, the biologists placed a polarizing filter over moving beetles. If the filter was aligned along the sky's dominant axis of light transmission, the beetles kept moving in the same straight line. But if the filter was rotated ninety degrees, the beetles, too, suddenly veered off at right angles: an elegant demonstration of an amazing visual ability. ("Insect orientation to polarized moonlight," *Nature* **424**:33, July 3, 2003)

A Matter of Taste

Every slab of cheese is an entire community of organisms, and, as with many human communities, its character may not be appreciated by everyone. Take Stilton. Made under license by only six dairies in the English Midlands, it's one of those cheeses whose strong aroma and intense flavor some find delightful and others find repellent. But just what makes a Stilton a Stilton? Danilo Ercolini, a microbiologist at Federico II University in Naples, Italy, and his colleagues at the University of Nottingham in England aimed to find out.

Using the latest techniques of DNA analysis, the microbiologists identified the panoply of bacteria that, along with yeast and the essential *Penicillium* mold, give Stilton its complex taste. They also discovered that distinct regions of the cheese—the blue veins (caused by piercing the ripening curd with needles to aerate it), the creamy ivory core, and the natural crust—vary in acidity and oxygen content and harbor different kinds of bacteria. Several unexpected micro-inhabitants are worth noting: two harmless species of *Staphylococcus*, the usually unwelcome intestinal microorganism *Enterococcus faecalis*, and several species of *Lactobacillus*. The investigators aren't certain whether they arrive on the scene by surviving the milk pasteurization process or by being introduced through equipment or other sources.

All the interlopers can serve as starter cultures in fermented products, such as yogurt and salami, in which they control the development of flavor, color, and texture. Their roles in Stilton are unknown, but their presence or absence may help explain why different batches of the cheese made at the same dairy can have highly different characteristics. Can custom-inoculated cheeses be far behind? ("Bacterial community structure and location in Stilton cheese," *Applied and Environmental Microbiology* **69**:3540–48, June 2003)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

Stilton, anyone?

Let There Be Light

Some 380,000 years after the big bang, the universal fog lifted and the cosmic background radiation was set free.

By Neil deGrasse Tyson

In the beginning of everything, when the universe was just a fraction of a second old, a ferocious trillion degrees hot, and glowing with an unimaginable brilliance, its main agenda was expansion. With every passing moment the universe got bigger. But it also got cooler and dimmer. And for millennia, matter and energy cohabited in a kind of thick soup, in which speedy electrons continually scattered photons of light to and fro.

Back then, if your mission had been to see across the universe, you couldn't have. Any photons entering your eye would, just nanoseconds or picoseconds earlier, have bounced off electrons right in front of your face. You would have seen only a glowing fog in all directions, and your entire surroundings—luminous, translucent, reddish white in color—would have been nearly as bright as the surface of the Sun.

Eventually, right around the time the young universe reached its 380,000th birthday, its temperature dropped below 3,000 degrees. Electrons began to slow down enough to be captured by protons, thus bringing atoms into the world. With fewer unattached electrons to gum up the works, the photons could finally race around without bumping into anything. That's when the universe became transparent, the fog lifted, and a cosmic background of visible light was set free.

That cosmic background persists to this day, the remnant of the light left over from a dazzling, sizzling early universe. It's a ubiquitous bath of photons—massless vehicles of energy, always moving at the speed of light, which act as much like waves as they do like particles. As the cosmos continued to cool, photons that had been born in the visible part of the spectrum lost energy to the expanding universe and eventually slid down the spectrum, morphing into infrared photons. As their wavelengths grew in size, they became cooler, that is, less energetic, but they never stopped being photons.

> *Some of the static you hear on a walkie-talkie comes from the microwave remnants of the early universe.*

Today, some 13.7 billion years after the beginning, the photons that make up the cosmic background have cooled further still, shifting down the spectrum to become microwaves. That's how they got their modern moniker: "cosmic microwave background," or CMB for short. A hundred billion years from now, when the universe has expanded and cooled even more, astrophysicists will be writing about the cosmic radio wave background.

The temperature of the universe is directly related to the size of the universe. It's a physical thing. If the universe grows to twice its original size, all its free-traveling photons lose half their original energy. A growing universe forces a photon's wavelength to get longer, stretching along with the spandexlike fabric of space and time.

A photon's wavelength is simply the separation between one wave crest and the next—a distance you could measure if you had a small enough ruler. Because all photons move at the same speed, the shorter their wavelengths the more wave crests have to pass a given point in a given interval of time. Those are the higher-frequency photons. And a photon's frequency is a direct measure of its energy. That makes sense, too: the higher its frequency—that is, the faster it wiggles—the more energy it carries.

When an object glows from being heated, it emits radiation in all parts of the spectrum. But that radiation always peaks somewhere. The peak energy output of ordinary household lightbulbs lies in the infrared part of the spectrum, which people detect as warmth on the skin. But of course lightbulbs also emit plenty of visible light, or we wouldn't be buying them.

The peak output of the cosmic background has a wavelength of about a millimeter, which is smack-dab in the microwave part of the spectrum. The static you hear on a walkie-talkie comes from an ambient

bath of microwaves, a few percent of which are from the CMB. (The rest of the noise comes from the Sun, cell phones, police radar guns, and so on.)

The existence of the CMB was predicted by the Ukrainian-born U.S. physicist George Gamow and his colleagues in the 1940s, culminating in a 1948 paper that extrapolated the known laws of physics into the early universe. The foundation of those ideas came from the 1927 work of Georges Édouard Lemaître, a Belgian astronomer and Jesuit priest who is generally recognized as the father of big bang cosmology. But it was two U.S. physicists, Ralph A. Alpher and Robert C. Herman, both of whom had worked with Gamow, who estimated what the temperature of the cosmic background ought to be.

In hindsight, theirs is a relatively simple argument, one that I've already made. The fabric of space-time was smaller yesterday than it is today, and if it was smaller, basic physics requires it to have been hotter. So the physicists turned back the clock and imagined an epoch when the universe was so hot that all its atoms were completely ionized—when all atomic nuclei were laid bare and all electrons roamed free. Under those conditions, they hypothesized, photons would not have sped uninterrupted across the universe, as they do today. The photons' free ride today would have required that the cosmos get cooler—cool enough for the electrons to combine with atomic nuclei, forming atoms and allowing light to move without obstruction.

Although it was Gamow who suggested that the universe was once hotter, and that you could know the physics of the early universe, it was Alpher and Herman who calculated its temperature: five degrees Kelvin (five degrees above absolute zero). Yes, they got it wrong—the CMB is actually 2.7 degrees Kelvin—but together, those guys made an extrapolation unlike any other in the history of science. To take some basic atomic physics from a slab in the lab, and then deduce the largest-scale phenomenon ever measured, was extraordinary. Discussing the feat in his book *Time Travel in Einstein's Universe,* J. Richard Gott III, an astrophysicist at Princeton University, writes:

> Predicting that the radiation existed and then getting its temperature correct to within a factor of 2 was a remarkable accomplishment—rather like predicting that a flying saucer 50 feet in width would land on the White House lawn and then watching one 27 feet in width actually show up.

When Gamow, Alpher, and Herman made their predictions, physicists were still undecided about the beginning of the universe. In 1948, the same year Alpher and Herman's paper appeared, a rival, "steady state" theory of the universe was proposed in two papers published in England, one by the mathematician Hermann Bondi and the astrophysicist Thomas Gold, the other by the cosmologist Fred Hoyle. The steady state theory required that the universe, though expanding, had always looked the same. And because a steady state universe could not have been any hotter or denser yesterday than it is today, the Bondi-Gold-Hoyle scenario maintained, matter was constantly popping into our universe, at just the right rate to leave the expanding cosmos with a constant average density. By contrast, big bang theory requires that all matter come into existence at one instant.

Predicting the CMB was a shot

(Continued on page 70)

Hiroshi Sugito, *The Drive*, 2002

Something to Howl About

To earn her spurs as a tropical biologist, the author decided to study a parasite that even her colleagues wanted to avoid.

By Katharine Milton

Juvenile howler monkey is heavily burdened with bot fly larvae on its neck. Each larva develops in a pocket of the monkey's skin, conspicuous for its open breathing hole. The parasites take a toll on their hosts and can lead to death, particularly in immature or weakened individuals. This juvenile is only half the size of an adult; it probably weighs between six and eight pounds.

In 1974, as a greenhorn to the tropics, I traveled to Panama to begin a study of the dietary behavior of wild howler monkeys on Barro Colorado Island. The island was separated from the mainland in 1912, during the construction of the Panama Canal: its six square miles of forest now serve as a field station managed by the Smithsonian Tropical Research Institute. In my first exhausting but exciting weeks settling into new quarters and venturing on my own into the forest, I noticed that many howler monkeys had peculiar lumps under their fur, usually around the neck and throat but sometimes on the chest or stomach, on the back, even on a cheek or above an eye. The lumps were large, and they often made the monkeys appear grotesque. Infants looked as if they had two heads or a massive goiter; many adults resembled something out of B-movie sci-fi.

Curious, I asked other biologists on the island about the lumps. They, too, were fairly new to the site, but their answer was immediate: "Bot fly larvae." Bot fly larvae? Eek! I'd never heard of them, but they sounded pretty alarming. I learned that *Dermatobia hominis*, the "human" bot fly, is well known to science because of the diabolically clever way it finds hosts for its offspring. A female ready to deposit her [illegible] blood-sucking insec[illegible] mosquito. She grasps the insect—known in the trade as an egg porter—and holds it firmly in flight while she attaches rows of her eggs to its abdomen with a water-insoluble glue. She then releases the insect unharmed. Now, though, it is neatly decorated with twenty-odd bot fly eggs. There the bot fly embryos grow quietly until they're ready to hatch.

The trigger for hatching comes from a third animal species. When the egg porter makes a meal from the blood of a mammal—a meal required for the insect's own reproduction—the bot fly embryos, by now developed into tiny threadlike larvae, sense the heat from the mammal's body and burst from their eggs. The larvae burrow directly into the mammal's skin, where they make themselves at home.

Each larva lives in what is known as a warble, a pocket or chamber that forms in the host's skin. In its warble, which has a small breathing hole open to the air, the larva feeds on a

rich soup of tissue fluids produced by the host. There the larva passes through three more "instars," or developmental stages, growing larger all the while. At the end of the third instar, the larva wriggles out of its warble, falls to the ground, and burrows into the soil to pupate. Some weeks later an adult fly emerges from the soil to seek a mate, and the cycle is repeated. Because most egg porters are not picky about whose blood they sip, the larvae of *Dermatobia hominis* can end up on almost any warm-blooded animal—from a squirrel to a monkey to (as the name implies) a human being. Double Eek!

My fellow scientists on the island regaled me with dramatic tales of intensely painful bot fly larvae growing in inaccessible places, in disgusting places, in very private places. According to these battle-scarred veterans, the best way to get rid of a larva is to plaster a thick piece of bacon on your skin above the breathing hole of a larva's warble. In desperation (since bot fly larvae have to breathe), the larva crawls out of its warble and up into the bacon. Then you whip off the bacon with the larva trapped inside. Poor howler monkeys, up in the trees with no bacon, nor even with the manual dexterity to force larvae out of the warbles by hand—my heart went out to them!

I went on with my field study, and months went by. Thankfully, I acquired no bot fly larvae, and neither did anyone else on the island. In fact, none of the other monkey species on the island—capuchins, spider monkeys, tamarins—were infested with bot fly larvae either, even though during some months virtually every howler monkey I saw bore multiple warbles. The other biologists noticed the same thing. As it turned out, none of these scientist-raconteurs had ever gotten a *Dermatobia* larva on Barro Colorado Island; all their exciting stories were based on experiences elsewhere in the neotropics. Perhaps these larvae were not that same notorious pest after all.

A veterinarian friend in Panama named Nathan B. Gale, the director of the Veterinary Public Health Laboratory, took an interest in the problem. Sick or wounded wild animals were occasionally brought to his clinic for treatment, and when a howler monkey arrived one day, he removed its bot fly larvae, put them in a preservative, and mailed them to an entomologist friend at Washington State University in Pullman, the late E. Paul Catts. Catts recognized that they were larvae of an entirely different species, *Alouattamyia baeri*, the howler-monkey bot fly. That was a big surprise, but also a big relief: the reason only howler monkeys were afflicted with the larvae was that the bot fly is host-specific.

Catts had written an extensive review describing the members of Cuterebridae, the New World family to which both *Dermatobia* and *Alouattamyia* belong. From Catts's review it was clear that *Dermatobia* is a maverick. Other species in the family tend to associate closely with just one mammalian host, typically a rodent or rabbit. In general, they also place their eggs not on egg porters but rather in areas of habitat likely to be visited by the host. A rodent bot fly, for instance, might leave its eggs on grass or twigs near the trail of its specific rodent host. When the rodent passes by, the heat from its body alerts the larvae, which emerge instantly from their eggs and attach themselves to the animal's whiskers or fur.

Howler-monkey bot fly larvae (upper photograph) are pictured at the third-instar stage, the last stage before pupation. Starting out cream colored (left), the third instar puts on additional weight and darkens (right). A fully developed larva is nearly an inch long and can weigh more than a tenth of an ounce. Male howler-monkey bot fly (lower photograph) has a distinguishing stripe on each eye. The insect is about seven-eighths of an inch long.

In most cases the larvae enter the host's body not by burrowing directly into the skin but by passing through the nostrils, eyes, or mouth. Larvae then spend several days migrating through internal organs and tissues, finally coming to rest at a preferred site on the host's body. The neck region is the most frequent target for the howler-monkey bot fly larva, but wherever it settles, it opens a breathing hole and ensconces itself in its warble to mature, a process that takes six or seven weeks.

So little was known about *Alouattamyia baeri*, however, that I decided I was in an ideal place to study its life cycle. My first task was to find out what the adult fly looked like. No one in Panama, including me, actually knew. The thing to do was to collect some larvae and wait for them to mature.

Collection was easy enough. The larvae were plentiful on recently dead howler monkeys in the forest or howler monkeys temporarily captured for marking or weighing. When fully developed, the larvae were black and heavily corrugated, resembling miniature hand grenades [*see upper photograph on this page*].

But getting the larvae to mature was less straightforward. I set up two screened enclosures where they could pupate, one in the forest and another in a well-aired room. All I had to do, I assumed, was check them each day and collect my adult

Howler monkey rests in a Cecropia tree, whose young leaves as well as flowers and fruits are an important source of food.

flies as they emerged from pupation. But day after day the enclosures remained empty. After nearly five weeks of waiting, I was almost positive that humidity and fungi had killed all the pupae. Then on the forty-eighth day, when I went to check the screened enclosure in the room, I found a large fly buzzing around inside. My captive was more than half an inch long, covered with short, dense, velvety black hair, and had transparent, amber-brown wings. My joyful cries alerted everyone within shouting distance to come and see this amazing fly. I named her Lucille.

The life of "Lucille, the Famous Fly," as she became known to everyone on Barro Colorado Island, may have been a happy one, but it was not long. Flies of the Cuterebridae family emerge from their pupal cases, mate, and die in just a few days. Just three and a half days after Lucille first appeared, I witnessed her death throes. The cause was old age. It was a sad moment. Her pinned remains still occupy a place of honor in my office in Berkeley.

About a year later I began a research collaboration with Douglas D. Colwell, a bot fly expert at the Lethbridge Research Centre in Alberta, Canada. In Panama Colwell and I collected more than fifty third-instar larvae, and he took them back with him to his lab in Canada. Colwell proved to be a deft hand at raising flies. Ultimately he was blessed with fifteen males and nine females. The female flies were noticeably larger, and their eyes spaced more widely apart. The live male bot flies had a red vertical stripe on each eye—a striking characteristic that fades and disappears after death [*see lower photograph on preceding page*]. (Lucille lacked this distinction, by the way, confirming that she was a female, and thus correctly named.)

Bot flies at Lethbridge were willing to mate, and each female deposited, on average, 1,400 black, ridged eggs, in rows of about 250 each. The females preferred to lay their eggs in the creases of moist paper towels. (For the laboratory bot flies that was the end; no monkeys were used in these experiments.) We have still not found the bot flies' site of choice for egg laying in the natural environment, though our prime suspects are tree leaves and branches.

No one has seen *Alouattamyia* mate in the wild, but males in the Cuterebridae family typically develop more quickly than females do, and then gather in trees or other high places. Again, no one knows why, but perhaps males in a group can attract more females per male, on average, than a single male could acting alone. That would improve each male's chances of mating, despite the competition. In any case, unmated females that fly near the group appear to have some way of advertising their virgin status, and the waiting males pursue them. When a male succeeds in clasping a virgin female, the pair alights to complete copulation.

Although the details of bot fly life history fascinated me, I particularly wanted to understand the interactions

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of howler-monkey bot flies and their hosts. Received entomological wisdom holds that a "prudent" parasite does not kill its host. Such restraint might seem particularly important for a host-specific parasite such as *Alouattamyia*. After all, if the parasite eliminates its natural host, it has nowhere to raise its larvae.

Yet many of the dead howler monkeys I found in the forest still bore a large number of bot fly larvae—ten or more. Because one third-instar larva can weigh more than a tenth of an ounce, ten larvae would be a heavy metabolic load, particularly for an immature monkey. My census of howler monkeys, about 1,200 individuals, also showed the proportion of juveniles was suspiciously low. Although about 300 infants were born each year, I estimated that there were only about 150 juveniles in the population. Perhaps, at times, "prudent" parasites weren't being quite prudent enough.

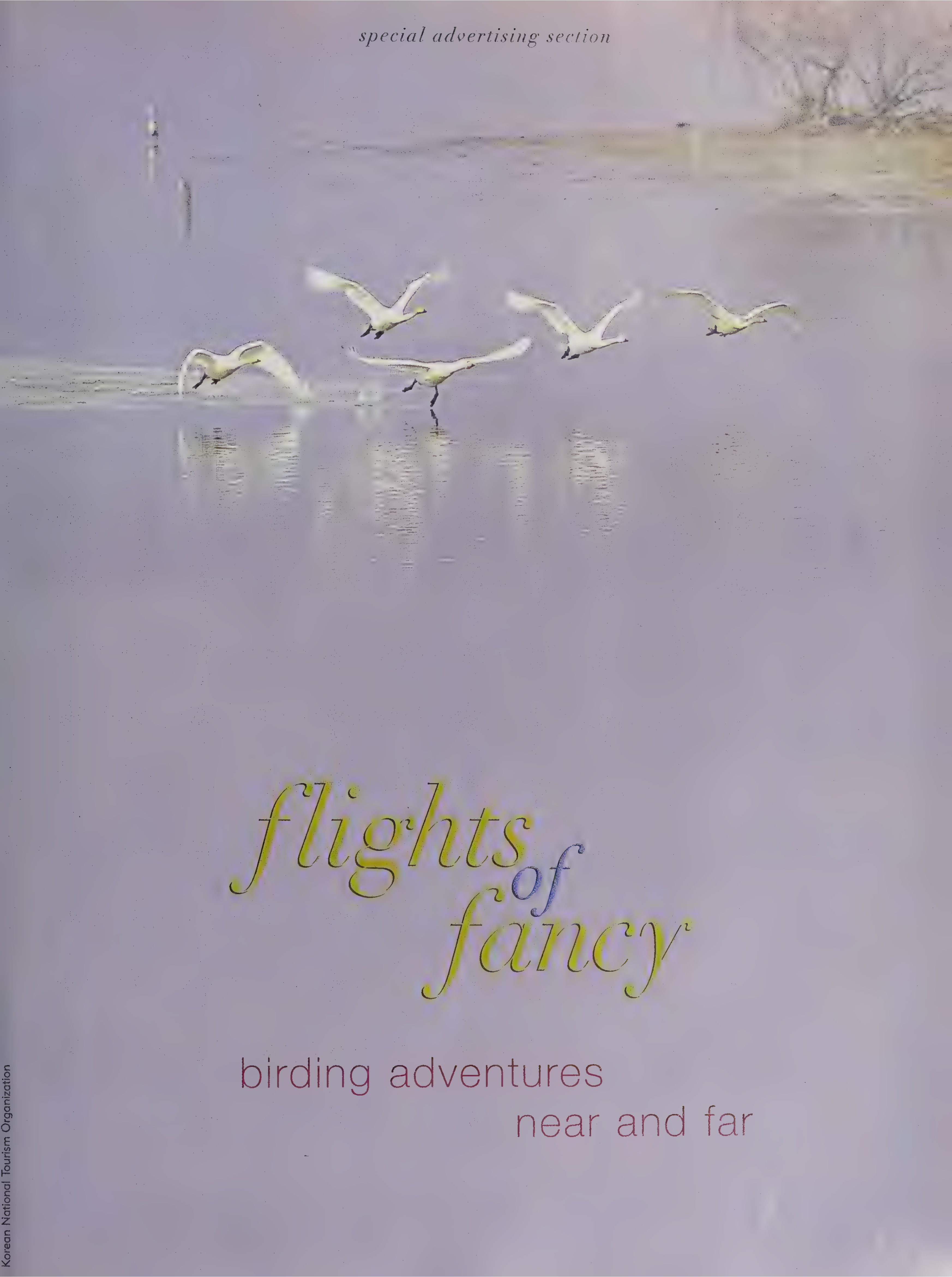
For the next five years I kept a monthly record of the number of bot fly larvae present in a representative sample of howler monkeys. I found a few afflicted monkeys in every month of the year, but the infestations seemed to peak two or three times a year, both in the number of monkeys afflicted and in the average number of bot fly larvae present on each monkey. The peaks came during the rainy season, which lasts from May through November, though the largest of them usually did not take place until July or later.

Throughout that same five-year period I also kept track of howler-monkey deaths. Scientists and visitors on the island alerted me or my assistants whenever a monkey was found dead, and we collected the remains. Although the procedure couldn't give us a complete tally of deaths, it did enable me to chart the pattern of annual mortality. The death rate was highest in July through November—the mid- to late-rainy season. At that time of year the energy-rich fruits and protein-rich young leaves the monkeys prefer to eat are in short supply. Were the high death rates caused by a food shortage, or by the cool, wet, cloudy weather? Perhaps those factors played a role, but, by themselves, they probably weren't sufficient: I found no overt signs of starvation or illness in the population. But I did note that bot fly larva infestations peaked at the same time.

A more complete account of the higher death rates probably goes something like this: The immune system of a howler monkey in good physical condition appears able to limit the number of larvae that can establish themselves at any one time. But howler monkeys in poor condition seem in jeopardy. Repeated attacks by bot fly larvae may exhaust the howler monkeys' fat reserves, which would normally carry them through the annual food shortages. Immature or fat-depleted hosts would be particularly at risk; combined with the stresses of cool, wet weather and low-quality food, many such monkeys would die.

Our data on infestation and mortality, as well as similar accounts of other bot fly–host interactions, suggest that populations of howler monkeys and their bot flies swing up and down like many other populations of predators and their prey. When the howler monkeys increase in number, all else being equal, the density of the howler-monkey bot flies increases as well. At times, though, the bot flies escalate their numbers out of proportion to their hosts. That leads to the deaths of so many howler monkeys that their population drops. But here the bot flies pay for their violation of the "prudent parasite" rule. They die off for lack of hosts. Hence the infestation rate drops, and the howler monkey population gradually recovers.

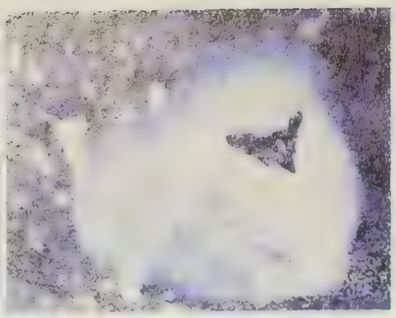
Katharine Milton is a professor in the Department of Environmental Science, Policy and Management, Division of Insect Biology, at the University of California, Berkeley. She has been studying the ecology and population dynamics of howler monkeys on Barro Colorado Island for thirty years.



flights of fancy

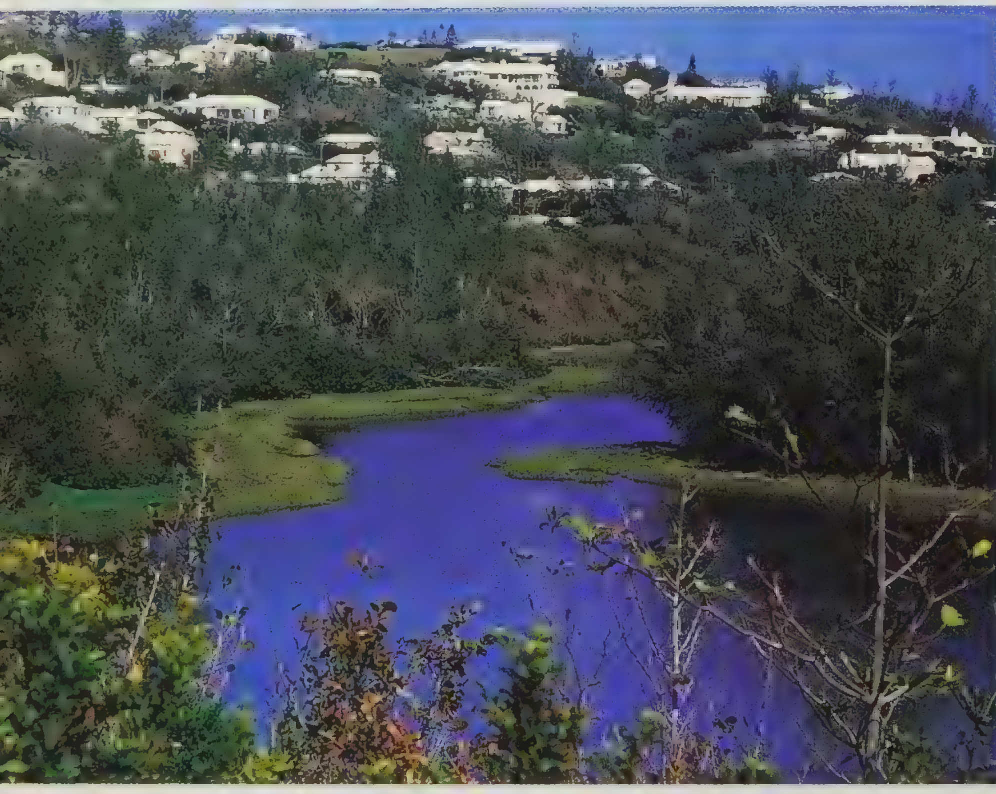
birding adventures near and far

Korean National Tourism Organization



Photos: Bermuda

BERMUDA



THE SUBTROPICAL ISLAND OF BERMUDA is a haven for birds and birders alike. Be prepared to spot a wide variety of birds—350 species have been recorded in this twenty-one-square mile paradise. The bright, lemon-yellow great kiskadee is both easy to spot and easy to hear. Listen for the loud, distinctive kis-ka-dee call that gave this raucous bird its name—it sounds uncannily like "*Qu'est-ce que dit*" in French. A member of the flycatcher family, the kiskadee was introduced into Bermuda in the 1950s and is now a year-round resident. Look for it in trees and shrubs or diving for fish.

Bermuda's most famous bird, the Bermuda petrel, or cahow, is a rare but rewarding sight. Considered extinct for 350 years, it was rediscovered in the 1950s. The petrel has a wingspan of thirty-six inches and nests in burrows on the East End islets from November through May. If you're lucky, you'll see this nocturnal bird soaring over the ocean at dusk.

Bermuda's native bluebirds can be seen in the many bluebird boxes lining the golf courses (every course on the island has a monitored bluebird trail). The island also has a population of white-tailed tropicbirds, known as the Bermuda longtails. With a three-foot wingspan and two long, streaming tail feathers, these birds are easy to recognize.

In the fall, Bermuda is a rest stop for birds migrating from Canada to South America. Thirty species of shorebirds regularly stop here. Look for them at Spittal Pond, Warwick Pond, and Seymour's Pond. Spittal, the best birding site in Bermuda, is also home to the greater flamingo. In autumn its mudflats host migrant shorebirds including plovers, yellowlegs, and sandpipers, and warblers are common in woodlands at both ends of the pond. You may also find cuckoos, kingbirds, flycatchers, swifts, swallows, orioles, and tanagers in the fall. Look for great blue herons among the reeds and shallow waters of Bermuda's marshes, or watch ruddy turnstones digging for food on the beaches.

With world-class resorts, sumptuous meals, turquoise waters, excellent snorkeling and scuba-diving, and a host of other attractions, it's not surprising that visitors return to Bermuda year after year!

Photos: Patricia Bradley

THE CAYMAN Islands

Birders in the know are finding their way to Cayman Brac, one of the three Cayman Islands.

CAYMAN BRAC, A SMALL ISLAND IN THE western Caribbean Sea, is one of the least explored birding destinations in the West Indies, but it is a birders' delight: miles of trails through tropical forests and coastal woodlands, good roadside viewing, and lots and lots of birds. In fact, 180 of the Cayman Islands' 224 bird species are found on the Brac.

One of the best times to visit the Brac is between August and May, when large numbers of migrants flock to the island, joining resident seabirds, wetland species, and an interesting combination of endemics. Don't miss *Amazona leucocephala hesterna*, the Brac parrot, the smallest member of the green Amazon parrot family. This parrot's size, coloring, call, and habits make it very different from its cousins on Grand Cayman, Cuba, and the Bahamas, so much so that if studies on its genetic makeup confirm that its genes are as distinctive as the rest of its attributes, it will become a new species. Look for this near-threatened parrot in the forests of the Parrot Reserve, established by the National Trust.

In the fall, parrots are seen everywhere on Cayman Brac. After months of child-rearing duties at the nest, the pairs emerge to teach their offspring the do's and don'ts of life in the forest. They fly from one fruiting tree to another; favorites include red birch, pepper cinnamon, wild fig, mangoes and papaya. Because they are creatures of habit, the parrots can be seen at regular sites as they fly to and from their breeding and roosting sites.

To see the five species of land birds that occur together on the Brac—Caribbean elaenia, vitelline warbler, thick-billed vireo, red-legged thrush, and Brac parrot—would otherwise require visits to the Swan Islands, coastal Central America, Cuba, and the Bahamas. The thrush is sartorially elegant in gray and black, with red legs and bill. It is usually noisy and bossy, but from November to January it becomes silent and disappears into the forest.

In between birding outings, try a little snorkeling or diving on the Russian wreck. You might go fly- and deep-sea fishing; photograph iguanas, orchids, and butterflies; or visit historic houses, caves, and the museum. And then there are the sunsets!

Next vacation,
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And let a friend go as well.
www.caymanislands.ky

Korean National Tourism Organization

Korea

LOOKING FOR A BIRDING VACATION off the beaten path? Why not visit Korea, with some 400 bird species and fantastic opportunities to see some of East Asia's greatest birds?

Birdwatchers have discovered that Korea's extensive tidal flats, along with one of the world's steepest tidal ranges, make it a fantastic place to watch shorebirds. Add good roads with English signs, excellent public transportation, and a network of ecotourism groups, and you have a first-class birdwatching destination.

At the bird sanctuary on Bamseom Islet, high-powered binoculars allow glimpses of many species of ducks and raptors. Seosan Reclamation Lakes/ Cheonsuman Bay is probably Korea's best site for wildfowl. In winter, it's easy to see raptors, Oriental white stork, and white spoonbills. Large flocks of waterfowl—peaking at 300,000 birds in November—soar over the site's two main lakes. The Iron Triangle Battlefield, in Cheorwon, Gangwon-do, is a paradise for migratory birds. Located within the DMZ, and uninhabited by humans in the last 50 years, this site is a popular stopover for ash cranes and eagles.

For more information on birding [illegible]com.

Queen Anne's County

LOVELY AND HISTORIC QUEEN Anne's County, a gateway to Chesapeake Country, is also a fine site for birding. Start your visit in picturesque Kent Island, established in 1631. Across from the island, in Grasonville, you'll find the Horsehead Wetlands Center.

Operated by the Wildfowl Trust, this 500-acre sanctuary has trails around six waterfowl ponds, each representing a different wetland habitat. You're likely to come across red fox, river otter, geese, and swans. Native waterfowl include northern shovelers, redheads, wood ducks, and tundra swans. The ponds also attract black ducks, canvasbacks, American wigeons, lesser and greater scaups, green- and blue-winged teal, cinnamon teal, and herons. Migratory birds traveling north and south on the Atlantic Flyway also stop here.

Don't skip the visitor center, where a powerful scope overlooks a waterfowl pond. The center also boasts an aquarium with critters from the Chesapeake Bay. Other must-see sites include Terrapin Beach Nature Park, with a one-mile nature trail, a pond, and two observation blinds. Look for birds of prey, migratory birds, and breeding waterfowl.

Garrett County

GARRETT COUNTY, the westernmost county in Maryland, boasts extensive and exceptional birding hot spots. This frontier region's state parks and forests are ablaze with beautiful foliage, crashing waterfalls, and clear lakes.

Because of its geographical location and topography, Garrett attracts many birds not usually found at this latitude: Garrett is the only place south of the Mason-Dixon Line where you can see birds usually seen in Canada, the Great Lakes, and the Northeastern states. Discover the hermit thrush in shady maple and hemlock groves, bobolinks in golden hay fields, northern water thrush in swamplands, and hawks migrating in autumn.

Spring and fall bring swarms of migrant flocks. The seven local lakes are a stopover point for thousands of feeding, migrating waterfowl, while the forests are filled with migrant songbirds.

With more than 140 species of breeding birds, including 28 species of breeding warblers, Garrett County is indeed a birder's paradise. To get the *Birds of Garrett County* brochure, stop by the Garrett County Visitors Center. And ask about the many state parks that conduct birding programs.

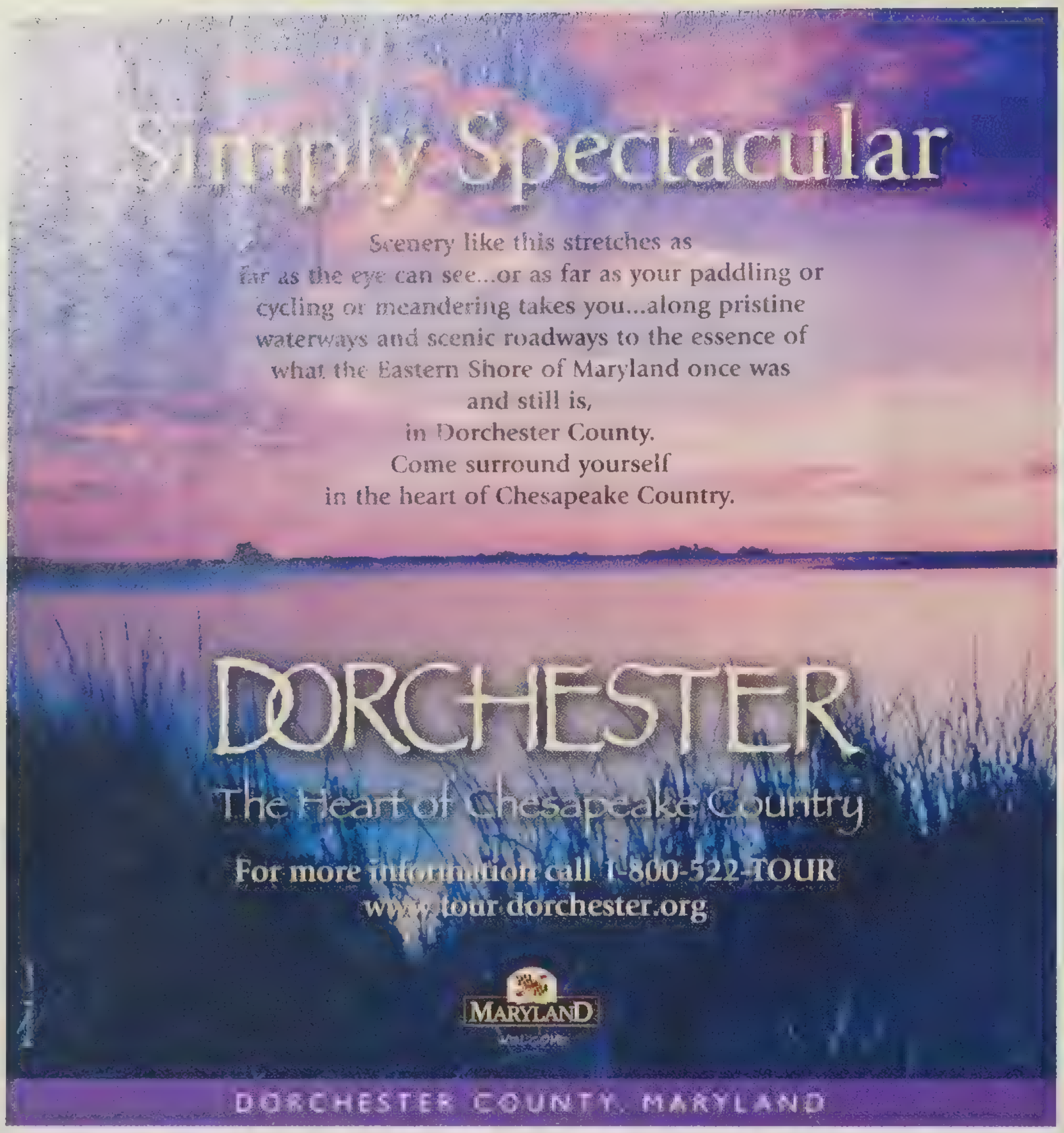
Worcester County

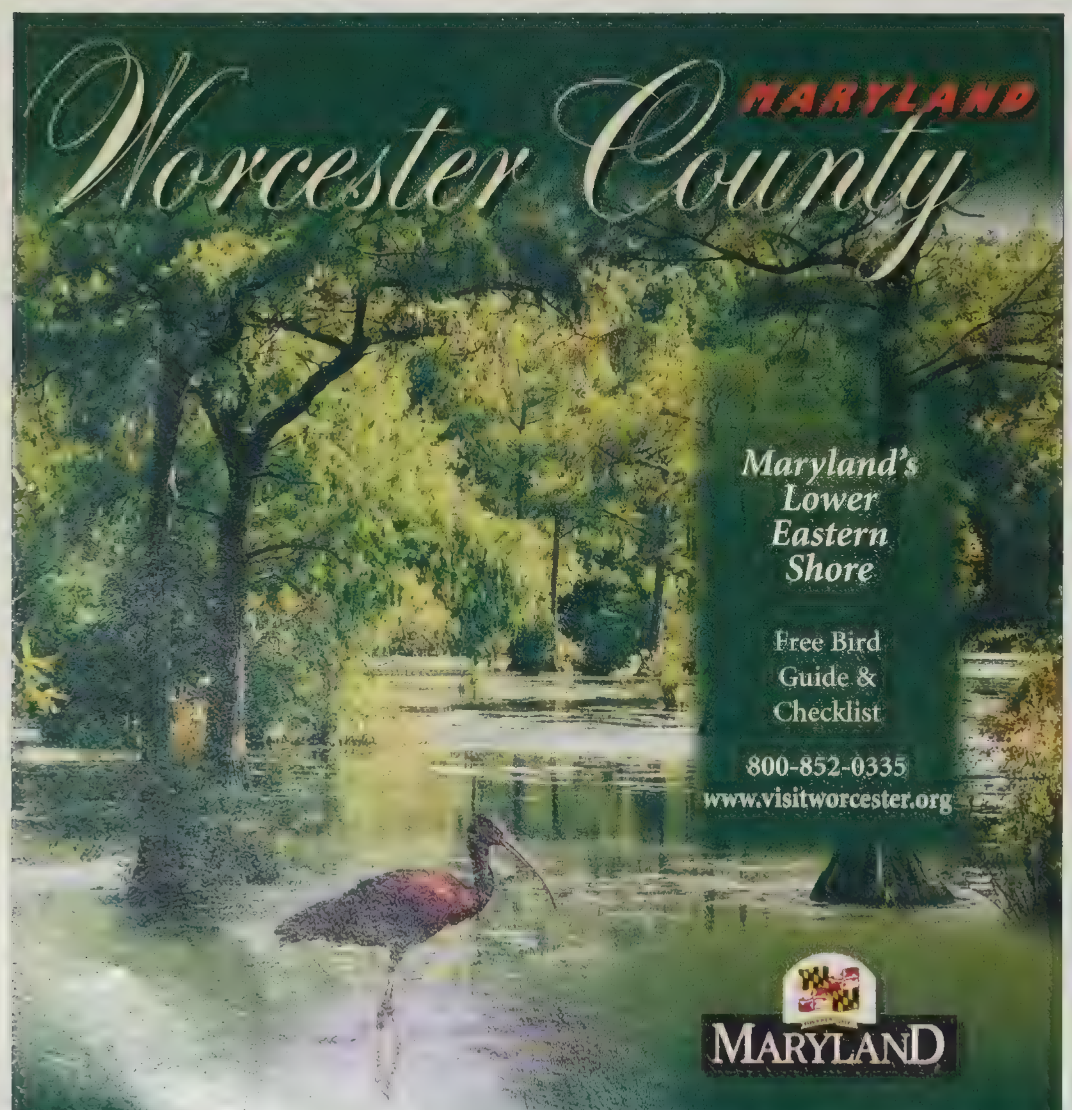
THE ONLY OCEAN-FRONT COUNTY in Maryland, Worcester County is especially known for the sandy beaches and boardwalk of Ocean City and the wild ponies that roam the dunes of Assateague Island. But Worcester is also a great place for birdwatching. With its great ecological diversity—the county is home to a barrier island, a cypress swamp, centuries-old forest, tidal wetlands, and secluded fields—Worcester hosts more than 350 species of birds.

Gerald Gerlitzki

In the fall, you'll spot myriad migratory species, including peregrine falcons, merlins, and flocks of tree swallows. If you are visiting Ocean City, take a birdwatching trip on a charter boat to see shearwaters, skuas, Wilson's storm-petrels, and Atlantic puffins. For those who prefer to stay on shore, Ocean City's bayside overlooks mudflats that harbor waterfowl, shorebirds, and gulls.

In the Pocomoke State Forest, the scenic Pocomoke River twists through stands of bald cypress. The best way to explore this spectacular river is by boat or canoe, which you can rent in Snow Hill. In addition to rare plants and wildflowers, you'll find hawks and ospreys lining the river and a host of waders along the shoreline. The Pocomoke Cypress Swamp is a major bald eagle roost; sometimes you'll find flocks of fifty eagles here.





Charles County

COME TO CHARLES COUNTY, THE gateway to historic Southern Maryland, and see the wild side of the Potomac! Visitors to this suburban county—less than an hour from Washington D.C. and historic Annapolis—are surprised to find it teeming with wildlife and natural beauty. Charles also offers first-class fishing, a dense population of nesting bald eagles, acres of beautiful forest land, 150 miles of spectacular shoreline, enough history to fill several books, sumptuous fresh seafood, and top-flight golf.


Charles County Office of Tourism

Among birders, Charles County is known for its large population of bald eagles, along with 321 other species. You can spot the eagles along winding Nanjemoy Creek, whose high banks protect their nesting sites. The creek also is home to ospreys and great blue herons. For 50 years, 2,500 herons have returned to the Nanjemoy Creek Great Blue Heron Sanctuary, operated by the Nature Conservancy, where they pair up, and lay and incubate a clutch of eggs. The mature forest along Mattawoman is home to the barred owl and vibrantly colored songbirds. A good time to visit is in the early evening, when you can hear the birds calling back and forth to one another. And the Chicamuxen Wildlife Management Area, near Mattawoman Creek, harbors rare species such as the Louisiana thrush.

Dorchester County

USFWS

FOR A TASTE OF CHESAPEAKE BAY tradition and the unique lifestyle of Maryland's Eastern Shore, come to Dorchester County. Bounded by the Choptank River and Chesapeake Bay, this gracious land welcomes you with the charm and simplicity of yesteryear.

Stop at the Visitor Center at Sailwinds Park to begin exploring the Heart of Chesapeake Country. Find the information you need, a waterfront boardwalk, a garden, a playground, and a spectacular view right on the banks of the Choptank.

Take in spectacular sunsets along 1,700 miles of shoreline. View many endangered species and hear the familiar calls of waterfowl at world-renown Blackwater National Wildlife Refuge, home to more than twenty species of ducks and eighty-five varieties of birds, including the American bald eagle.

Stroll along Cambridge's historic district, where stately eighteenth- and nineteenth-century homes grace brick-paved, tree-lined High Street. Let a historic tour—or even a ghost walk—take you back to this prosperous era. Visit the county's museums, which preserve its rich heritage. Explore the birthplace of Harriet Tubman and home of sharpshooter Annie Oakley.

At the end of the day, choose a retreat at a quiet inn or a luxurious resort in the Heart of Chesapeake Country.

BigPockets

BEFORE YOU EMBARK ON YOUR next birding or natural history trip, take some time to browse www.bigpockets.com or to request a catalog (877-247-3758). BigPockets is the first company to design and manufacture clothing specifically for birding.

To make shopping easy, the company arranges its catalog according to clothing, accessories, gear, and gifts. Going to Alaska in June? You'll find cozy jackets, sweaters, hats, gloves, foot warmers, and socks for your trip. Spending the summer at home? Check out the lightweight clothes that wick away moisture, sun block, sun hats, chigger repellent, and cool-cat collars. Going someplace wet? Big Pockets offers a waterproof field notebook and a pen that writes in the rain.

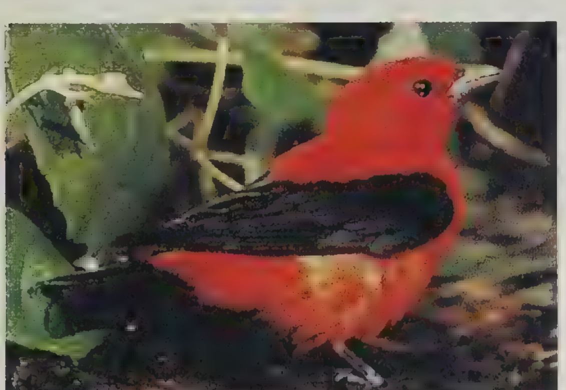
The company's most popular product, the BigPockets tropical vest, is virtually weightless, dries quickly, and takes up little space in a pack. The vest features ten big pockets to hold the largest tropical field guides plus binoculars, tickets, umbrella, repellent, and water bottles.

BigPockets sells great gifts for birdwatchers and other naturalists—from bird-friendly coffee and chocolate to stuffed toys for children. All products meet three criteria: functional for birding, best in their class, and compact enough to fit in a suitcase or daypack.

The Johns Hopkins University Press

FOUNDED IN 1878, Johns Hopkins is one of the largest and most reputable university presses in the country. Birders will be especially interested in the press' many books on Chesapeake natural history, including *Birds of the Mid-Atlantic and Where to Find Them*, by John Rappole, the only comprehensive field guide to bird life in the area that also directs readers to public sites where each species can be found. Rappole, a noted ornithologist, provides extensive information about every species: description, identification details for distinguishing similar species, habitat preference, vocalization, range, and Mid-Atlantic seasonal occurrence, abundance, and distribution. Each entry is accompanied by a color photograph, making identification easy for amateur bird watchers, and by a range of maps. A helpful guide to sites lists the best places to spot specific birds, from common species to rarities, and how to reach the sites by car.

For more information about the Johns Hopkins University Press, visit http://www.press.jhu.edu/press/index.html, where you can browse the catalog of 2,000 books in print.

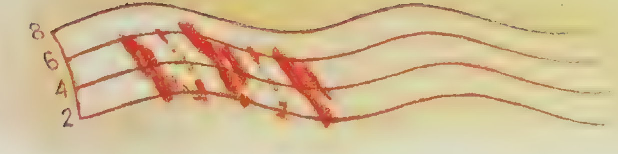


And Don't Miss...

ANNE ARUNDEL COUNTY—On the shores of the Chesapeake, this Maryland county is home to historic Annapolis, America's sailing capital, and the Patuxent Research Refuge, which harbors over 200 bird species—including a pair of bald eagles that has been nesting here since 1989!

LITTLE ST. SIMONS—This private Georgian isle offers seven miles of pristine beaches and an unhurried pace. Located on the Atlantic Flyway, the island is a critical staging area for migratory birds. Flocks of shorebirds appear every fall.

TALBOT COUNTY—Discover the unspoiled beauty and maritime heritage of Maryland's Eastern Shore, and take the longest cable-free ferry in the U.S. to Oxford, once a major shipbuilding center.



Evolutionary Anthems

The songs of Darwin's finches might be responsible for the group's rapid speciation.

By Adam Summers ~ Illustration by Mick Ellison

On Santa Cruz Island, in the eastern Pacific Ocean, the morning sounds of songbirds foraging and courting are reassuringly familiar in the otherwise outlandish landscape of the Galápagos Islands. The dry washes here partly conceal tortoises the size of refrigerators; iguanas as long as your arm sprawl in the baking sun. Darwin's finches, one of the best-studied examples of rapid speciation, are the source of the early morning's whistles and trills. But the birds are far more than mere pleasant diversions that remind homesick biologists of their own territorial origins. Rather, already famous as the subjects of long-term studies on feeding adaptations and the origins of species, the birds are proving to biomechanists that their calls represent a mechanical link between foraging abilities and song production. The co-variation of song and beak size may have been the driving force behind the rapid evolutionary development of finch species in the small island chain, a process that took less than 3 million years.

Speciation—how [illegible] species gives rise [illegible]other—is [illegible] to grasp for [illegible] that beco[illegible]lated. Imagine that an earthquake upends enough rock to create rapids in a formerly sluggish stream (a common event in South America). The new stretch of rapids could keep fish upstream of the rocks from mating with their downstream counterparts. Inevitably, over the generations, the two groups will have to contend with differences between the two habitats—whether in dissolved oxygen levels, water temperature, food availability, or the presence of parasites. Those selection pressures—as well as the simple accumulation of diverse mutations—may be enough to genetically isolate the upstream from the downstream population.

Speciation without physical separation, however, is a trickier concept. Species arising by such a process are known as "sympatric," a term whose Greek roots mean "of the same country." The finches of the Galápagos present a textbook example of sympatric speciation. One common ancestor gave rise to fourteen distinct species, even though members of the ancestral population were within easy flight of one another—in other words, even though there was no geographical barrier to interbreeding.

Thirty years of fieldwork, molecular biology research, and morphological study have led to a good understanding of the evolutionary history of Darwin's finches, particularly the link between their food habits and the shapes of their beaks. Today's birds descend from a generalist ancestral finch that invaded the islands from mainland Ecuador. Galápagos species now inhabit a variety of ecological niches, and each species has a beak suited to finding food in its niche: insect-eating species, for example, have narrow, warbler-style beaks, useful for nabbing insects from leaves and bark; seedeaters have robust bills, tough enough and strong enough to crack the hard seeds they favor. Now the variations among Darwin's finches have enabled Jeffrey Podos, a behavioral ecologist at the University of Massachusetts in Amherst, and colleagues at Duke University to prove that a bird's beak is as vital to its song as to its supper.

The clear tones of birdsong emerge from internal air sacs that can inflate and deflate, much like a bagpipe's bladder. Muscles surrounding the sacs force air through a part of the bird's respiratory tract

called the syrinx, a thin-walled region of muscle and cartilage roughly analogous to human vocal chords. As it passes through the syrinx, air vibrates at several dominant frequencies and many overtones, blatting as though it were blown through the mouthpiece of a trumpet. And, just as in a trumpet, the tone of the sound is profoundly affected by the length and shape of the resonating chamber "downstream" of the original vibrations. In the bird's case, the vocal tract acts as a long, fleshy resonating chamber, damping out many of the overtones. By rapidly opening and closing its beak a bird can alter the damping characteristics of the vocal tract.

Podos and his colleagues demonstrated in the laboratory that when sparrows sing, their beaks partly determine the tone of their call. The slower the beaks move, the simpler is the melody of the call, both in tonal range and rhythm. The next step was to study birdsong in the field, focusing on several species of closely related birds with varying beak shapes and sizes.

Mechanical systems usually have to sacrifice force for speed. That constraint is particularly telling in biological mechanical systems—where, for instance, jaws that can move rapidly cannot close with a lot of force. Podos realized that among Darwin's finches, the varieties of this trade-off and the natural variability of beak shape could enable him to test whether a bird's song could indicate the bird's ability to eat hard seeds. With Joel Southall, also at the University of Massachusetts, and Marcos R. Rossi-Santos of Projeto Baleia Jubarte in Caravelas, Brazil, Podos filmed the calls of seven species of Galápagos finches. The birds ranged from the warbler finch *(Certhidea olivacea)*, with a pointy, narrow beak [*see illustration on opposite page*] to the large ground finch *(Geospiza magnirostris)*, with a broad, heavy bill [*see illustration below*]. The results meshed well with the laboratory data. The heavy-billed birds had simpler calls, presumably because the bill, more suited for closing forcefully on a tough seed, was not able to move as rapidly as the more delicate beak of the insect eaters.

One of the chief roles of calls among songbirds is to find mates, and that takes me back to the topic of sympatric speciation. When that first population of generalist finches invaded the Galápagos, natural variation in beak size among individuals would have made the tougher seeds an accessible food item for some of the animals but not for others. Because song pitch and beak strength are interrelated, those birds would also have sung a slightly simpler, deeper song than their smaller-beaked brethren. Many female birds prefer males with a familiar call—their own—and so heavy-beaked females would have preferred the song of heavy-beaked males. The link between song and food could thereby lead to segregated mating within a population, even though all the individuals in the population could freely mix.

Ah, the sweet sound of evolution in action!

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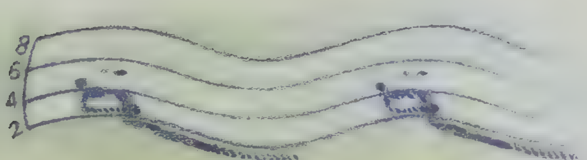


A bird's song is determined by the interplay of its vocal tract and its beak. The songs of Darwin's finches, whose vocal tracts are basically identical, differ mostly because of the birds' beaks. At the same time, the beaks largely determine the finches' diets. Jeffrey Podos demonstrated that a finch's song could predict the hardness of the seeds the bird could eat. The thin, fast-moving beak of the warbler finch (Certhidea olivacea) [see illustration on opposite page] *pitches the bird's song as high as nearly 8,000 hertz—almost three octaves above a soprano's high C—whereas the robust beak of the large ground finch* (Geospiza magnirostris) [see illustration at right] *limits the bird to a less variable melody that rarely breaches 2,000 hertz. The sound spectrograms next to the birds are not musical scores; rather, they portray, from left to right, how the frequencies of the birds' songs, in thousands of hertz, change with time.*

Portal to Petra

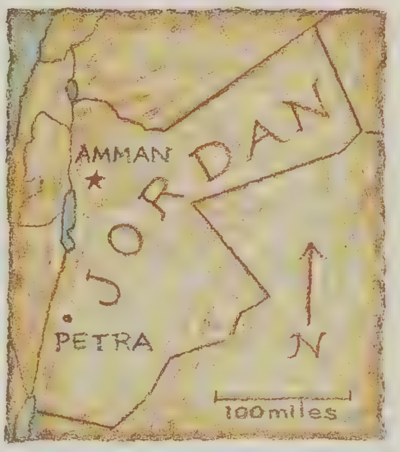
Hewn out of sandstone cliffs, the hidden capital of the ancient Nabataeans became a center for spice traders, artisans, and urbane sophisticates 2,300 years ago.

By Martha Sharp Joukowsky

Iridescent as a ribbon of silk fluttering in the air, the Silk Tomb (above) of the ancient city of Petra (see map at right), is named for the iron oxide striations in the sandstone monument. The Silk Tomb, which dates to the first century B.C., actually housed several burials and is one of the most distinctively colored rock-cut monuments of the Nabataean culture that made Petra its capital city.

Towering high above the Wadi al-'Arabah, a seasonal streambed that runs between the Dead Sea and the Gulf of 'Aqabah, in southwestern Jordan, majestic cliffs strike the eye with their patterns of russet and gold. Yet tucked inside the sandstone cliffs is a site even more thrilling to travelers, adventurers, and archaeologists: the "Rose-Red City," Petra.

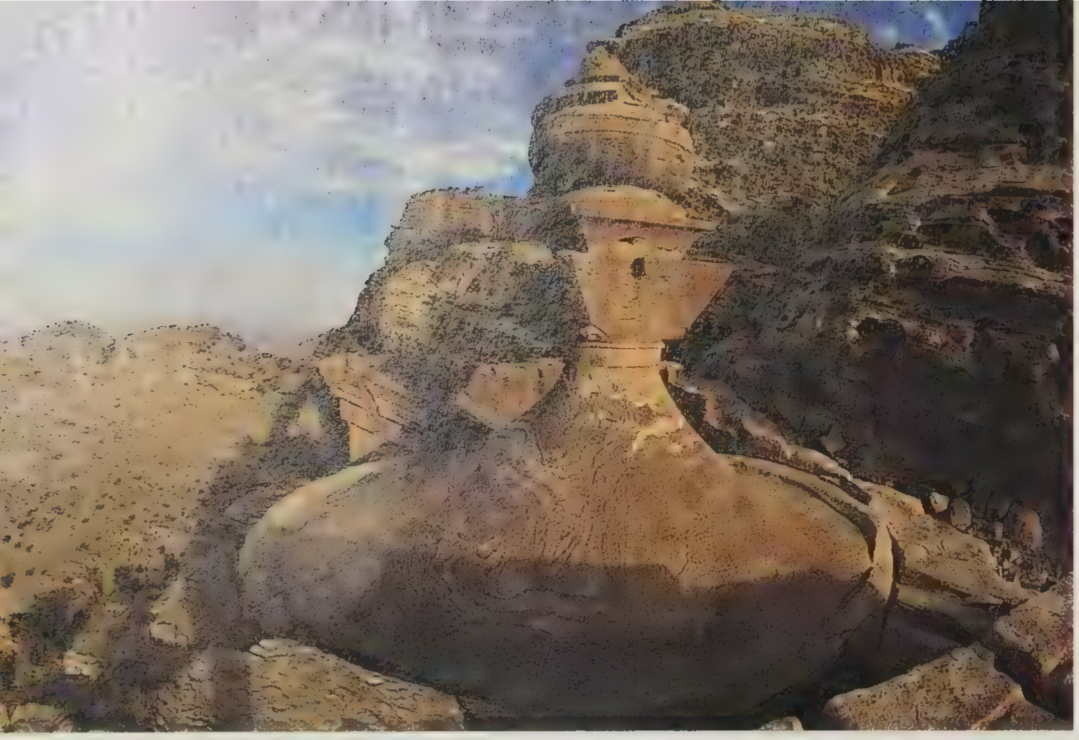
Beginning in perhaps the seventh or sixth century B.C., nomadic Arabs from as far away as the southern reaches of the Arabian Peninsula threw up temporary shelters against the mountain walls around the site of what would become the city. According to a fourth-century B.C. Greek account reported by the first-century B.C. historian Diodorus of Sicily, the earliest Petrans, or Nabataeans, as the people were then called, did not plant grain, fruit trees, or vines. But they did raise camels, which provided them with milk, cheese, and meat, as well as hides for tents. Sometime in the second century B.C. the Nabataeans and their camel caravans attained wide-ranging economic success through their control of the spice trade routes. The Nabataean dominance extended over the southern routes through the Arabian Peninsula, to Amman and Damascus to the northeast, and through the Negev desert and into the Sinai to the west, as far as the western edge of the Nile delta.



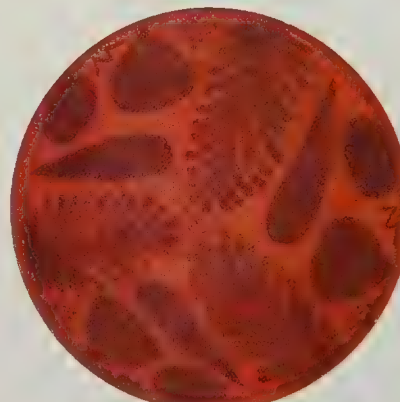
Petra was the capital of the Nabataeans' independent kingdom, and as Greek and Roman demand for such exotic goods as cassia, cinnamon, frankincense, and myrrh increased, so did the prosperity of the Nabataeans. They excavated the cliffs to build some 800 tombs as well as numerous extraordinary freestanding structures. Their hydraulic engineers dammed nearby water sources and built massive cisterns for retaining the infrequent rains. With a reliable water supply, they irrigated crops and sustained a growing population, estimated at its peak to have been between 20,000 and 30,000 people.

As their trade expanded, the Nabataeans borrowed artistic styles from Hellenistic, Parthian, and Roman cultures, adapting them to their own eclectic style. They so prized foreign goods that, according to the ancient Greek geographer Strabo, "they conferred honors on anyone who increased them" (though Strabo adds, in wonder, "they have only a few slaves").

An earthquake in A.D. 363, one of several that was to strike Petra, may have precipitated the city's demise. By that time, trade no longer centered on Petra, and its population had declined. Christianity flourished in the waning days of the city, which survived well into the sixth century. In the eighth century, another earthquake struck, but by that time the city had been abandoned. □



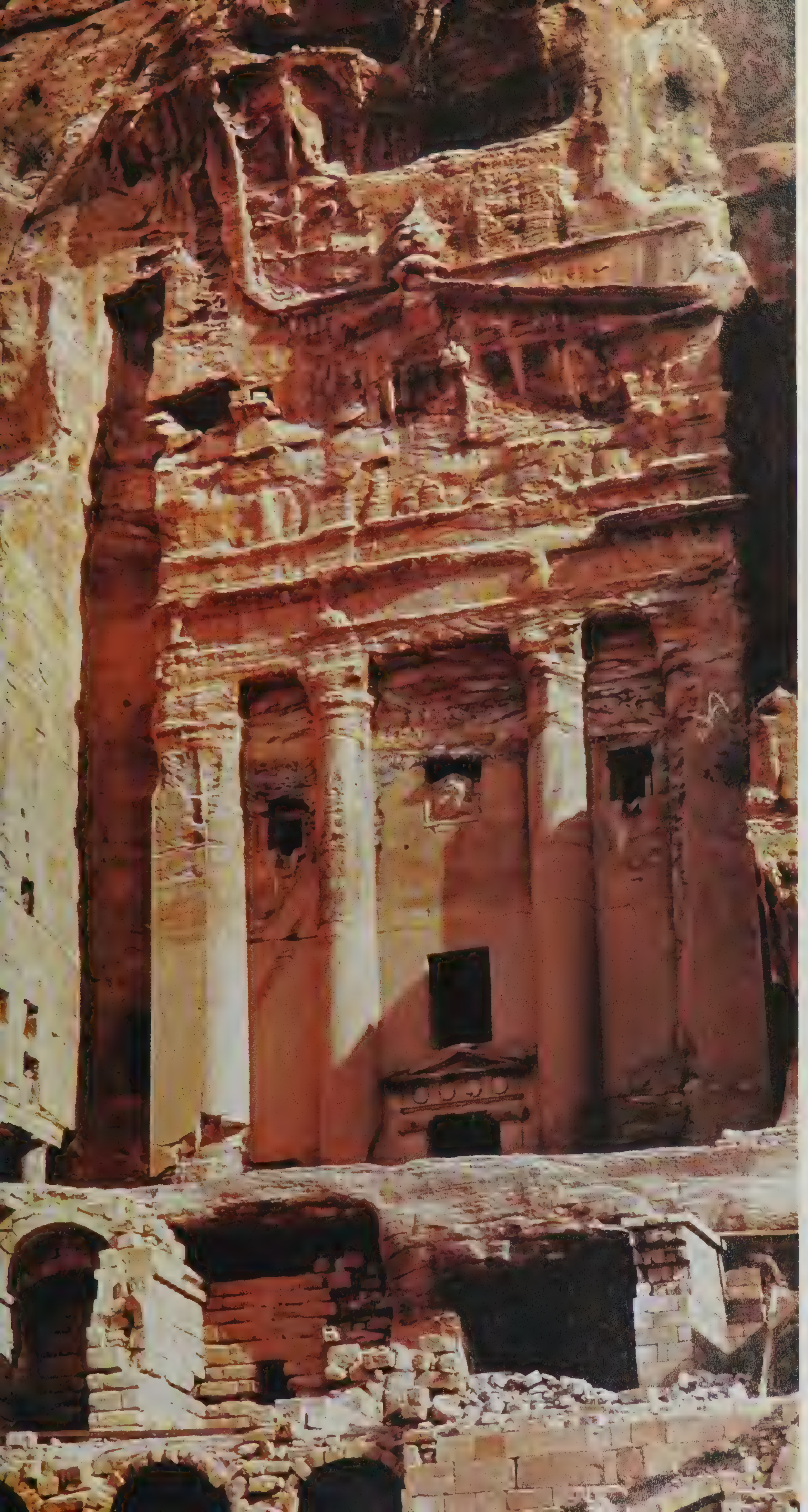
Urn carved out of the rock wall decorates the top of the Dayr, or "monastery," Petra's largest rock-cut monument. From this high perch, some 150 feet above the valley floor, visitors can take in the site of Petra and its vast surrounding landscape.



Nabataean plate displays typical decorative motifs of the culture, including figs, olives, and palm leaves. The Nabataeans were renowned for their extraordinary ultrafine pottery bowls and plates, decorated with designs unique to the Nabataean culture.

Betyl, or stone idol, dated to the first century B.C., depicts a stylized human face that may represent one of the great goddesses of Petra. A "house" for the god is indicated by the [illegible] and architectural details around the edge. The [illegible] reads: "Goddess of Hayyan, son of Nybat."

Terra-cotta plaque from the first century A.D. depicts a male pipe player accompanied by a pair of female musicians. The Nabataeans often had large gatherings at mealtime, and one ancient writer commented that it was common to have two female singers at each banquet.



Mosaic roundel, from the floor of the sixth-century Church of Petra, may depict a camel, the backbone of the Nabataeans' successful trade in exotic spices. Alternatively, it may depict a "camelopard," the name the Greeks and Romans gave to the giraffe, which they described as a camel with the spots of a leopard.

The Urn Tomb, so-called for the small vessel carved at the top of the facade (toward the center, near the top) is one of the largest of Nabataean rock-cut monuments. Architects first removed a large section of the hillside to create a seventy-foot courtyard in front of the tomb. The central niche, seen below the pediment, may have been the tomb of King Malik II, who ruled from A.D. 40 to 70.

Promised Land

Several million years ago tectonic forces began to create an edenic corridor that led early humans out of Africa and into the Near East.

By Zvi Ben-Avraham and Susan Hough

Straddling the border between Israel and Jordan, deep within a region torn by decades of political strife, is the stark, desolate, intensely saline Dead Sea. Virtually barren of life, and imbued with a stillness that bespeaks extreme antiquity, the Dead Sea, in geologic terms, is actually quite young—a mere several million years of age. Both the sea itself and the entire Dead Sea valley in which it lies are the result of north-south motion at the boundary between two tectonic plates—two parcels of the Earth's rocky crust.

Continents might appear to be indestructible, but when tectonic forces pull blocks of crust in different directions, eventually even a continent will break. Until 20 million to 30 million years ago the African and Arabian plates were a single massive block of our planet's lithosphere. But then the floor of what soon became the Red Sea began to spread—launching the Arabian plate to the north-northeast, toward Eurasia; breaking the small Sinai subplate away from the African plate; and tearing up Earth's crust along the way.

Nowadays the Arabian plate is diverging from the Sinai subplate at a rate of about four millimeters a year. That's slow even by geologic standards (and a dozen times slower than human fingernails grow), but given enough time, even a slight but continual movement of a tectonic plate can cause inexorable, prodigious changes. In the past 20 million years or so, the Red Sea has opened, the Arabian Peninsula has taken shape, and the eastern flank of the Dead Sea fault has shifted about sixty miles northward with respect to the western side—enough to sculpt the Dead Sea valley, a long, prominent path through the landscape of the Levantine Corridor [*see map on next page*]. From that distant time until what was, geologically speaking, yesterday, the Dead Sea valley became the main land route out of Africa for both flora and fauna. Among the fauna, of course, were some of our earliest hominid ancestors. And as the geologic story of the Levantine Corridor has come into focus, an intriguing plotline has emerged: for perhaps the first time, investigators have shown that large-scale geologic processes have helped shape the course of human history.

Like so much else in nature, the topography of the Earth eschews straight lines. When a markedly linear feature does emerge, say from a subtle topographic trend discernible only in a satellite photograph, the trained eye of a geologist invariably sees an active fault—a feature along which earthquakes persistently recur. But you don't have to be a geologist to see the Dead Sea fault zone. Viewed from high above, its linear morphology, running up the middle of the Levant, is a dramatic—and decidedly unsubtle—indicator of its geologic character [*see illustration at left on page 47*].

The tectonic forces on the Arabian plate and the Sinai subplate are pulling in slightly different directions, and at different rates, creating what geologists call a transform fault [*see diagram at right on page 47*]. From the Dead Sea the fault extends almost due south to the Red Sea, and almost due north along the Jordan River and up into Lebanon, eventually wending its way into southern Turkey. Flanked by margins as high as 7,000 feet above its floor, the rift valley created by the Dead Sea fault is one of the deepest and most abrupt depressions on Earth.

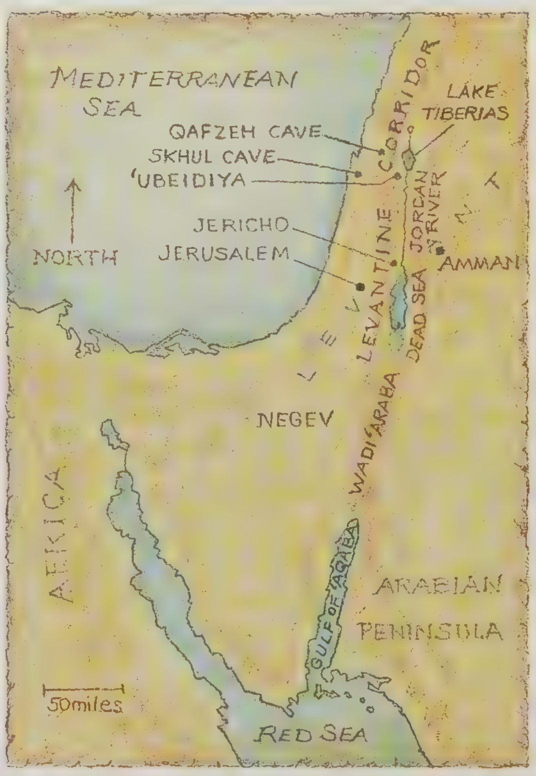
Investigators can point to compelling evidence for ancient, damaging earthquakes in the anthropologically and archaeologically crucial area bordering the Jordan River. The first-century A.D. Jewish historian Flavius Josephus, writing of the destructive earthquake of 31 B.C., describes "an earthquake in Judea, such as had not occurred before, which killed many cattle. . . . And about thirty thousand persons also perished in the ruins of their houses." Characteristically toppled and fractured blocks of limestone that were once columns are evident among the ruins of early Jericho and elsewhere. And the sediments in the Dead

Dead Sea valley, a once-verdant corridor that runs through the region just east of the Mediterranean Sea, was the land route taken by hominids emigrating from East Africa, beginning about 2 million years ago. Today the valley is arid and thinly populated, and the Dead Sea, which lies at its heart, is inhospitable to most forms of life.

Sea basin incorporate evidence of a good deal of seismic upheaval during the past 70,000 years.

For now, however, the Dead Sea rift valley offers geologists a nearly unparalleled opportunity to see and investigate continental breakup in action. Natural processes can be studied here without impediment, because the area is both sparsely populated and largely free of vegetation. The shores of the Dead Sea itself are the lowest dry land on Earth, and among the Dead Sea valley's unique characteristics is that, even though it has sunk to hundreds of feet below sea level, much of it is not submerged. Rock formations are thus well exposed.

Tens of millions of years ago, before the Arabian plate set off on its Eurasian journey, the Mediterranean Sea was far bigger than it is today, and covered much of the Levant. Later activity at the boundary between the Sinai subplate and the Arabian plate caused major upheavals of the seabed; between the two plates a block of crust sank, forming a valley known as a graben. As the huge, salty Mediterranean evaporated and receded, that graben retained some of the water. Eventually the large body of salty water that occupied most of the Dead Sea valley shrank because of evaporation. Several lakes subsequently appeared and disappeared in the rift valley; the present Dead Sea, comprising two sub-basins, was left behind about 10,000 years ago. Its northern sub-basin was, and remains, by far the deeper: it now holds less than a thousand feet of water, and its bottom lies about 2,350 feet below sea level. The much shallower, southern sub-basin is now dry.



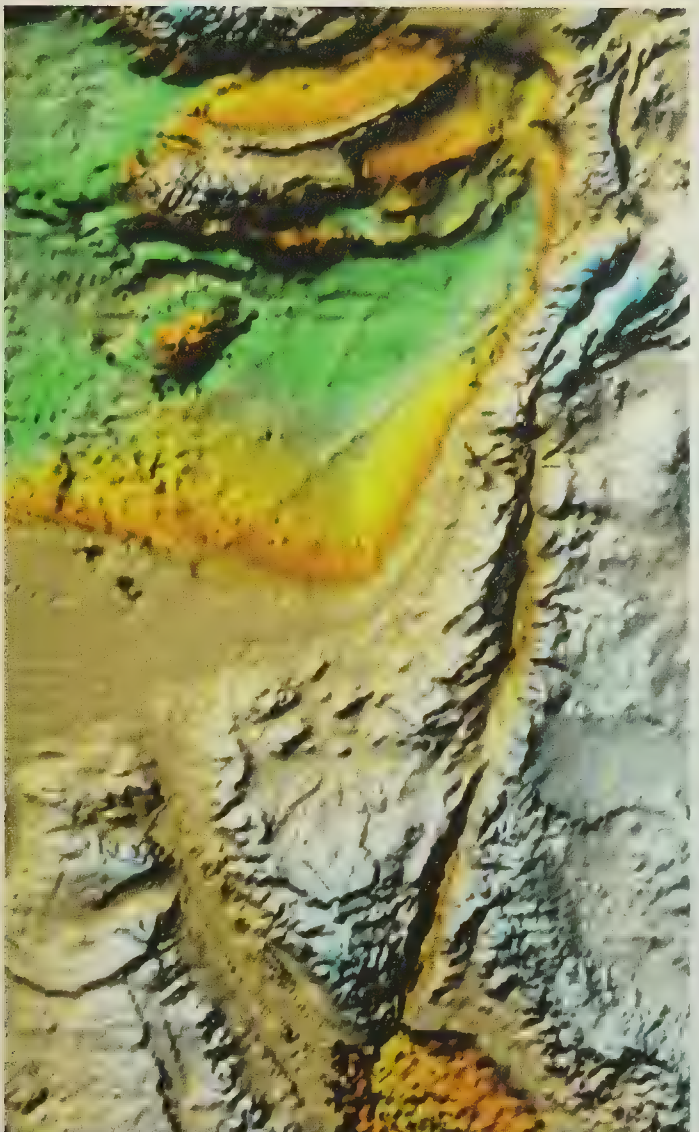
Geologists have devised a number of clever ways to reconstruct the past movements of tectonic plates. One important clue comes from estimating the rate at which sediments were deposited. Investigators have found that the upper, hence later, layers of sediment in the Dead Sea valley built up more quickly than the lower, earlier layers. Hence the water that carried the sediments from higher land to the flat valley floor must have flowed more quickly as the millennia passed. That implies the surrounding landscape was becoming increasingly mountainous. Accordingly, geologists have inferred that before about 5 million years ago the entire Dead Sea fault zone was relatively flat, but that in the past 2 million to 3 million years, accelerating tectonic processes have strongly uplifted its flanks.

There is further evidence of rapid change in the Wadi 'Araba, or Arava Valley, the southern part of the Dead Sea valley, which reaches from the southern end of the Dead Sea to the Gulf of 'Aqaba. In the past 2 million years the Wadi 'Araba subsided, as the neighboring Negev region to the west—as well as the Trans-Jordanian plateau to the east—was uplifted and tilted. Here, as elsewhere, seemingly gradual geologic motion has led to dramatic cumulative changes. In the blink of a geologic eye the Dead Sea transform fault carved up enough of the landscape to reconfigure the patterns of river drainage in the Negev desert. As a result, within just the past 2 to 3 million years sizable freshwater lakes formed in newly created depressions in the Wadi 'Araba.

The appearance of large bodies of freshwater in an otherwise arid zone invariably gives rise to a wetter, more temperate local climate. The air becomes more humid because of evaporation from the lakes, and large bodies of water also tend to buffer the extremes of hot and cold, making the region altogether more inviting and hospitable to terrestrial life.

In the southern Levant the new lakes would have beckoned to flora and fauna alike, just as in more recent times in North America, trailer parks have sprung up near new bodies of water such as southeastern California's Salton Sea (suddenly created as a result of an engineering gaffe combined with major flooding on the Colorado River in 1905). Of course Airstreams and RVs were hard to come by during the Pliocene and Pleistocene Epochs, but the migrating creatures of Africa, including early modern humans, gradually made their own kinds of living arrangements near the lakes that appeared in the rift valley. Thus did the Dead Sea fault carve the land route out of Africa: a navigable, habitable corridor flanked by raw, rugged rock.

We *Homo sapiens* are descended from bipedal primates—usually called hominids—that first appeared in Africa some 5 million years ago. The

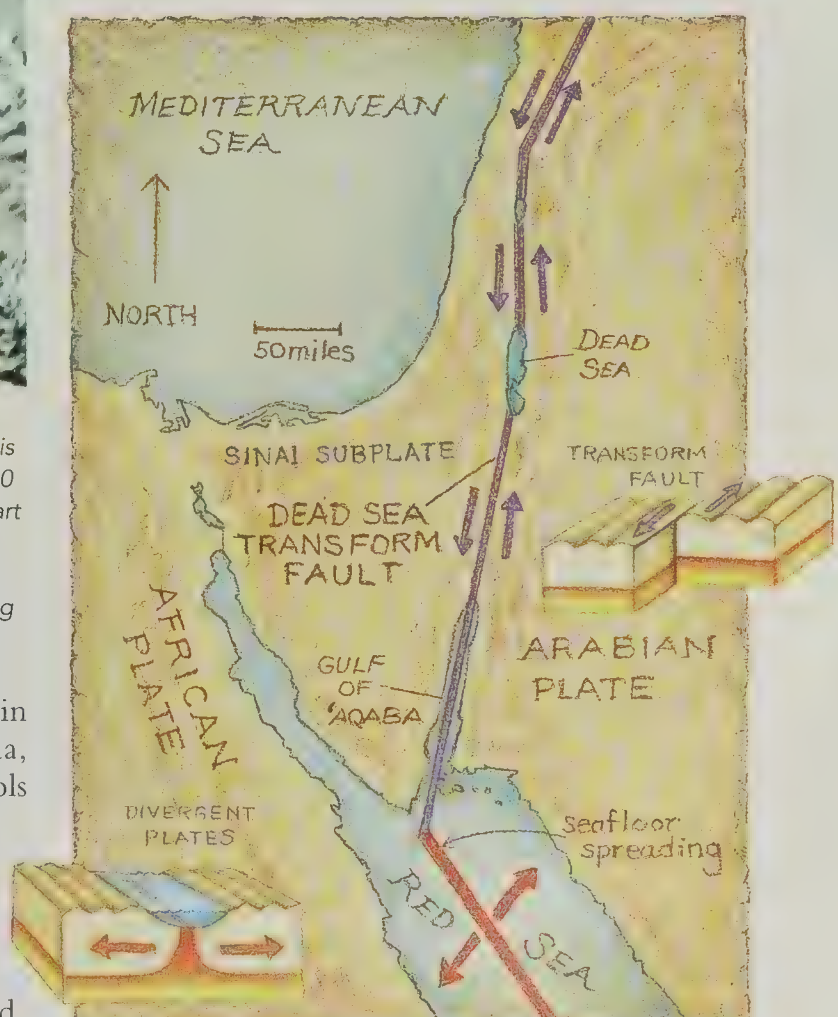


Dead Sea transform fault, the nearly linear north-south boundary between the Arabian plate and the Sinai subplate, is clearly visible in the topographical relief model (above). For 20 million years the floor of the Red Sea has been spreading apart and the Arabian plate has been pivoting northward with respect to the Sinai subplate and its parent, the African plate (right). By 2 million to 3 million years ago the movement along the fault had created a deep, lush, navigable valley.

earliest hominid remains have been unearthed in East Africa—that is, in present-day Ethiopia, Kenya, and Tanzania. The earliest hominid tools that appear to be part of a standardized tool-making tradition were discovered in the same region: hand axes related to the Acheulean culture. Such axes were a Paleolithic invention—rounded at one end to fit in the palm, pointed at the other end, chipped and fractured to a cutting edge along the perimeter.

Early Acheulean axes, about 1.4 million years old, were found at Olduvai Gorge in Tanzania, the site made famous by the findings of the archaeologists Louis and Mary Leakey. Outside Africa the earliest hand axes whose dating is uncontested are also Acheulean and also about 1.4 million years old. They were unearthed in the Dead Sea valley about sixty miles north of the Dead Sea—at the extensive site of 'Ubeidiya, a vanished lake just south of what was once the biblical Sea of Galilee, now variously called Lake Tiberias or Lake Kinneret.

Excavations at 'Ubeidiya have uncovered the best available hard evidence for the migration of early hominids [*see "Down in the Valley," next page*]. Since 1960 some thirty archaeological layers, showing multiple distinct periods of occupation, have been exposed. On the basis of several kinds of converging evidence—magnetic characteristics of the rock layers, changes in sedimentation, ecological changes reflected in pollen grains, and deposits of bones, boulders, fossils, and tools—investigators have been able to date the occupations with confidence. Later sites elsewhere in the Dead Sea fault zone have yielded a wealth of additional evidence of hominid and human occupation, such as uncracked, hard-



shelled pistachios, acorns, and water chestnuts, accompanied by pitted stone hammers and anvils. The earliest known raisins and olives have been found in this region. And, tellingly, within natural oases are trees of Sudanese origin: emigrants from the southwest.

A million years ago, in Pleistocene times, when

freshwater was far more abundant than it is today, the Dead Sea rift valley would have been lush, verdant, and full of things for the indigenous fauna to eat. And the paleontological record clearly shows that the splendid new corridor attracted a remarkable influx of species—birds, mammals, invertebrates, plants—between 2 million and 3 million years ago. Arriving in step with East African flora were the creatures of the East African savannas: gazelle, giant deer, hippopotamus, rhinoceros, wart hog. Life arrived and blossomed once tectonic movements had pried the region's blocks of crust apart and tilted them to form mountains, providing the water from which all else flowed.

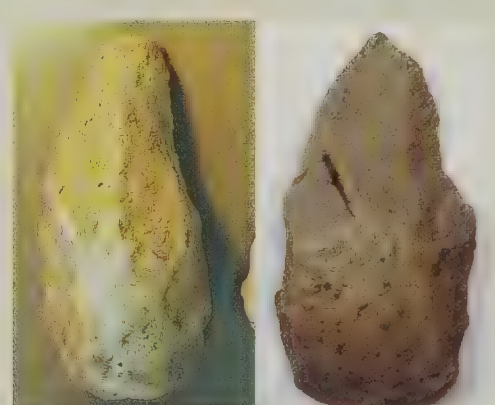
Today, unfortunately, that land of milk and honey is no more. The freshwater lakes that once dotted the Wadi 'Araba are permanently dry. The Dead Sea itself is nearly lifeless. Almost 35 percent (by weight) of its "water" is made up of dissolved solids—not

Down in the Valley

By John J. Shea

On the outskirts of Jericho, beside the road to Jerusalem, is a sign welcoming visitors to "the world's oldest town." "Oldest" hardly begins to say it. At least 1.8 million years ago—long before 12,500-year-old Jericho became the continuous habitation on which the sign stakes its claim—some of the first hominids ever to venture out of Africa probably walked through Jericho and drank water from its spring. The lakes that filled the valley of the Jordan River between 2 million and 3 million years ago formed a biogeographic corridor connecting hominid habitats in East Africa with the southern foothills of the Alpine-Himalaya mountain belt.

The earliest evidence for a human presence in the Jordan valley comes from the site of 'Ubeidiya, just south of Lake Tiberias (the Sea of Galilee) in northern Israel. There, stone tools and the fossils of large mammals occur together in remnants of a muddy shoreline about 1.4 million years old. Hand axes similar to the ones discovered at 'Ubeidiya occur throughout southern Eurasia, suggesting that the site records the passage of one of Africa's earliest emigrants, *Homo erectus.* (Earlier hominids, such as *H. habilis,* may have passed through the region en route to sites such as Dmanisi, in today's Republic of Georgia, but they left no trace of their sojourn in the valley.)



Acheulean hand axes from 'Ubeidiya in Israel (left) and Olduvai Gorge in Tanzania (right)

Stone hand axes, fashioned according to African techniques and found at a site just north of Lake Tiberias, suggest another round of emigration out of Africa about 780,000 years ago. Remains discovered west of Lake Tiberias at Skhul Cave and Qafzeh Cave indicate that early modern humans—probably either descendants or near relatives of the recently discovered, 160,000-year-old *H. sapiens* fossils from Herto, Ethiopia—were present in the Jordan River valley between 80,000 and 130,000 years ago.

Some 70,000 years ago Neanderthals arrived in the area, perhaps driven southward by the abrupt onset of glacial conditions; they probably competed with modern humans for caves and other habitats. Within 40,000 years Neanderthals had become extinct throughout Europe. The Jordan valley is one of the first places where modern humans developed strategies for displacing rival species and establishing dominion.

With the waning of the Ice Age some 12,000 years ago, hunter-gatherers living in the Dead Sea rift zone made some crucial innovations in the collecting of plant foods. The earliest levels of excavation in Jericho show that they gathered the seeds of cereal grasses from the rocky crags flanking the valley and planted them in fertile alluvial soil. The result: domesticated plants, followed centuries later by domesticated cattle, goats, and sheep, and the expansion of human settlements.

John J. Shea, a specialist in stone-tool analysis and in the Paleolithic period of the Near East and Africa, is a professor of anthropology at Stony Brook University in New York State. During the 1990s he codirected excavations at 'Ubeidiya, Israel; he is now codirecting excavations at Omo Kibish, Ethiopia.

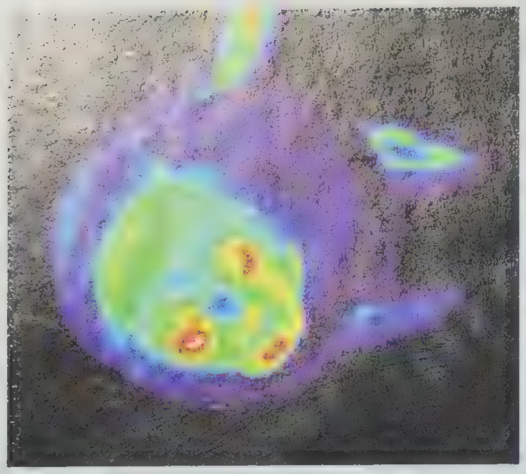
Dead Sea, the lowest, saltiest lake on Earth, was originally left behind in a deepening valley as the vast Mediterranean Sea retreated from the Levant between 5 million and 6 million years ago. The water level at the shoreline is about 1,360 feet below sea level, and it continues to fall because of evaporation, laying bare the saline, mineral-rich sediments visible in the photograph.

only sodium chloride but also potassium, bromine, and magnesium salts—giving it the highest salinity of any lake on Earth. With each passing year, evaporation further drops its level and raises the salinity of the remaining fluid. Since 1929, when hydrologists began keeping records, the Dead Sea has dropped by more than seventy feet. Only highly specialized communities of salt-tolerant microorganisms make their home in it today.

Scholars tend to seek meaning along sharply different timescales. A historian typically searches across decades or centuries for the written word. An evolutionary biologist may study a species across hundreds of thousands of years. A physical anthropologist considers the few million years that hominids have walked the Earth. The frame of reference for a terrestrial geologist may be longer still—as long as Earth's 4.6-billion-year history. The longest timescale of all is the cosmologist's 13.7-billion-year age of the universe.

Yet rarely, it seems, have the disciplines met. For the historian, the questions addressed by evolutionary biology, anthropology, geology, and cosmology have generally (except for the occasional natural catastrophe) fused with the unchanging background against which the real action takes place. Increasingly, though, physical scientists and historians are seeing connections. The physiologist and evolutionary biologist Jared Diamond of the University of California, Los Angeles, for instance, has advanced the thesis in his notable book *Guns, Germs, and Steel* that the exigencies of geography, if not geology, have played a critical role in shaping the development of cultures.

In the study of the Dead Sea fault zone, one can extend the connections further still. Creakingly slow geologic forces opened up the corridor for humanity's earliest ancestors to take their first steps out of Africa and into the world beyond. That exodus was probably inevitable, but the timing and direction of the migration were determined by plate tectonics. Perhaps it behooves our species, now poised to shape the planet in dramatic and potentially disastrous ways, to realize how fundamentally the planet has shaped us. □



Infrared image of a Weddell seal pup reveals the insulating efficiency of its lanugo, or baby fur. In the false-color image, shades of blue and green represent relatively low temperatures on the animal's surface; shades of yellow and red represent relatively high ones. The image shows that only the face and flippers radiate heat.

Sunbathing Seals of Antarctica

The puzzle is: How do they keep cool?

By Terrie M. Williams

Within an hour of the passing of a late October blizzard, there is little evidence of the storm on a vacant Antarctic beach. The bright Sun shines in a cloudless sky, and a light breeze riffles the clear waters of an open pool in the sea ice of McMurdo Sound. Weddell seals, spurred by the improved weather, haul themselves out of the water onto the icy edges of the pool. Each one, whether burly male, young female, or mother with youngsters in tow, claims an accustomed spot on the frozen shoreline. They settle on their backs into grooves in the ice that fit their bodies like familiar chairs. The adults soon doze soundly except for the occasional relaxed snore, while the energetic youngsters continue to play, popping in and out of the water. Finally exhausted, they crawl next to their mothers to sleep, their rounded bellies pointed directly toward the Sun.

For six years my colleagues and I have witnessed the spectacle of the sunbathing seals during the beginning of the austral summer, but never once have we considered joining them. After all, we are just 840 miles from the South Pole. As inviting as the pool appears, the "beach" where we are standing has been carved out of frozen sea ice by the constant summer sunlight and the movements of the Erebus Glacier ice tongue, near McMurdo Station. The Sun may never set, but air temperatures can plummet to –4 degrees Fahrenheit, and blinding snowstorms appear without warning. Sunbathing here can be risky business: even huddled in our parkas and boots, the members of our expedition live under the constant threat of frostbite and hypothermia.

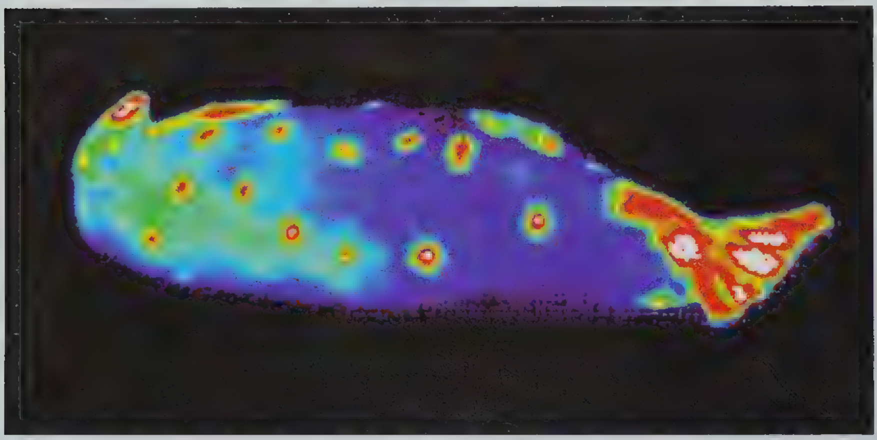
Remarkably, Weddell seals manage to thrive year-round on and under the sea ice, without shivering and without the long, thick fur characteristic of cold-adapted terrestrial mammals such as Arctic foxes and musk oxen. (The coarse, half-inch-long hairs of the Weddell seal pelt provide little in the way of insulation.) By any standard, that is an extraordinary thermal feat. Yet the very effectiveness of the insulation raises a puzzling question: How can a sunbathing seal in the Antarctic avoid overheating? The answer depends on an even more remarkable, if somewhat counterintuitive, physiological feat. Weddell seals have evolved a temperature-regulating system that enables them to keep warm in the coldest climate on Earth, yet remain cool enough to lollygag about in the summer air without even breaking into a sweat.

Our research team in Antarctica includes eight biologists who travel south every austral summer to study Weddell seals as they hunt beneath the sea ice. With the support of the National Science Foundation's Office of Polar Programs, we explore the seals' navigational abilities, predatory tactics, and diving capabilities. As the team's exercise physiologist, I am charged, among other things, with finding out how the seals maintain their relatively constant, hot internal temperature while they hunt and rest in water that would render a person hypothermic in minutes. As one might expect, the answer begins with fatty tissue: blubber.

In 2002 my graduate student Matthew R. Rutishauser and I arrived in Antarctica with several pieces of specialized equipment from my laboratory at the University of California, Santa Cruz. The first

Weddell seal pups such as the one in this photograph wear their fluffy lanugo fur coats for insulation until they reach about four weeks old. Thereafter they rely, as their parents do, on blubber to keep them warm in the water.

Adult seal, bleeding from the left foreflipper, may be sunbathing to recuperate from its wounds. The Sun's heat may stimulate an increased flow of blood, heat, and oxygen to wounded tissues, thereby promoting healing.



Numerous thermal "windows," which radiate excess heat, are apparent in this thermal image of a sunbathing seal. The animal can jettison excess heat though its face, foreflippers, and hind flippers. The hot spots along the body are bite wounds in the pelt.

was a portable ultrasound machine, originally designed for monitoring human pregnancies, that enabled us to view and measure the thickness of the blubber layer just below the skin of adult seals and their pups. The ultrasound scans showed a relatively uniform layer of blubber running virtually the entire length of the body, and ranging between 1.6 and 2.4 inches thick, in adults that weigh between 900 and 1,100 pounds. Even in one-month-old pups, which are the size of mature Saint Bernards, the blubber layer is between 1.2 and 1.6 inches thick.

Our second piece of equipment was an infrared thermal camera, which shows differences in temperature across the surface of an animal as a false-color image. We knew from earlier investigations that diving Weddell seals have a core body temperature that hovers around 97.7 degrees Fahrenheit. The camera would show us just how effective the fatty blubber was at keeping that heat from escaping into the ice and frigid Antarctic air.

The first seal I examined was a male that had recently emerged from a hole in the ice. At first the camera didn't even distinguish the wet animal from its frozen surroundings; the entire image was dark blue. Assuming the camera was working, the seal's skin temperature was the same as that of the ice—otherwise the batteries in the camera had failed in the cold.

Then the seal turned his head toward me and yawned; his hot open mouth glowed bright red in the image. Subtle surface temperatures soon became apparent. Hot nostrils intermittently popped into the picture each time he breathed. The skin around his eyes glowed as well, suggesting that surface blood vessels prevent the eyes from freezing as he hunts for fish in the chilly waters beneath the ice. The rest of the seal's thermal image was a ghostly blue, a testament to the quality of his blubber insulation.

In mid-October the Antarctic Sun sets for the last time for nearly four months. Throughout that period of uninterrupted daylight, Weddell seals haul their massive bodies through cracks in the sea ice or in the growing pools of meltwater, and onto frozen beds of ice. Too rotund to shake out the water quickly freezing onto their fur, the animals roll around in the soft snow, to "towel" themselves dry. Once settled, they lounge in the sunlight for hours, which sometimes dissolve into days. The Weddells often stay so long in one position that they melt into the ice, leaving telltale bathtub-size, seal-shaped imprints scattered across the frozen surface. Rather than avoid the intense solar radiation, the seals seem to revel in the sunlight. Only when temperatures dip below –4 degrees Fahrenheit, winds whip up above fifteen knots, or snowstorms blow across the ice, are the seals driven back into the water, where the environment is far more stable.

But if the blubber layer enables the seals to meet the thermal challenge of living in the frigid water under the ice, it also poses a double peril for their well-being. In the first place, we estimated it would take only a few hours of lying in the intense Antarctic Sun for Weddell seals to cook in their own skins. The second problem is that overheating would threaten reproduction, particularly the via-

bility of sperm. So the seals must get rid of the excess heat, but how? After all, they cannot shed their blubber, the way Matt and I take off our parkas when we get too warm. As it turned out, the solution to the puzzle of keeping sperm cool was the first step in figuring out how blubbery Weddell seals can spend days soaking up sunlight.

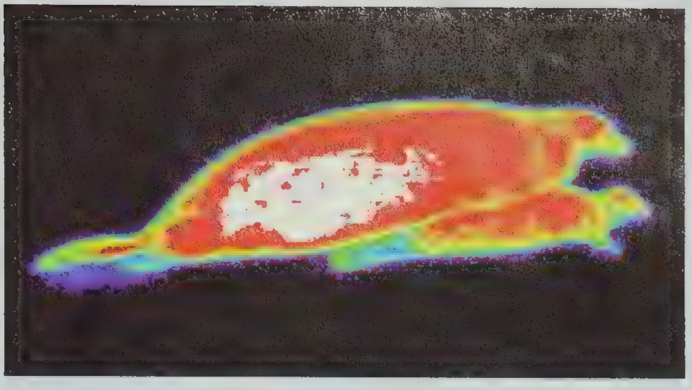
For a male mammal to produce viable sperm, the temperature of the testes must be precisely controlled; typically, it is several degrees cooler than the core body temperature. In land mammals, the testes remain cool because they reside in external scrotal sacs. For a mammal that lives in water, however—not to mention icy Antarctic waters—the same body plan would be a liability. A scrotal sac would expose the testes to extreme cold, and interfere with a sleek, hydrodynamic profile. Hence the testes of Weddell seals, like those of other seals and cetaceans, are internalized, lying between the abdominal muscles and the thick insulating blubber layer. Of course, that placement exposes sensitive organs to the risk of becoming too hot.

The problem is solved in seals with an elegant anatomical arrangement of blood vessels, first described by Sentiel A. Rommel, a comparative morphologist at the Marine Mammal Pathobiology Laboratory in St. Petersburg, Florida, and his colleagues. The investigators painstakingly mapped the seal's vasculature, and so discovered a dense network of veins enveloping the seal's testes. The network receives blood directly from the veins of the two hind flippers. Because the seal's layer of blubber does not extend to its flippers, veins in the flippers lie close to the surface of the skin, poorly insulated from the ice and cold water. Hence the blood in those vessels is cooled. On its return trip to the heart, the blood passes through the testicular net, cooling the testes.

The specialized arrangement of blood vessels gives the seals a thermal "window" through their insulating blubber, keeping temperature-sensitive reproductive organs cool. In the males, the window safeguards sperm production. In the females, an analogous vascular net helps regulate the temperature of developing fetuses.

Thermal windows—primarily through the hind flippers, but also through the mouth, eyes, and nose—seemed to us the most likely areas for dissipating the seals' excess heat. Rutishauser and I hoped to record those windows with our infrared camera, expecting to see dark blue insulated seal bodies punctuated with red-hot hind flippers. A dog in its winter coat displays a similar thermal pattern: seen with equipment similar to ours, a cool, insulated body fades into hot, thinly furred legs and paws.

To our astonishment, not only did the seals' flippers glow, but so did the rest of their bodies. And

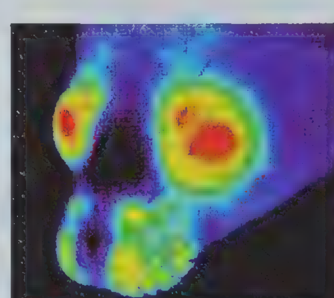


A mother and pup glow brightly in the infrared image. To sunbathe without becoming dangerously overheated, the animals cannot rely on thermal windows alone. Instead, their entire bodies act as radiators. Networks of arteries and veins close while the animals are underwater, but open to shed excess heat within an hour after a seal hauls itself out of the water.

Bathtub-shape grooves in the ice, in which seals lie during sunbathing, form from the intense heat of the seals' bodies. Their surface temperatures can rise by as much as fifteen degrees Fahrenheit in the first hour they spend out of the water.

the longer the seals were out of the water, the warmer their bodies became. We found that the stubby front flippers, the hind flippers, the nose, and the eyes glowed first. But then the back and belly warmed, too. Obviously, the entire body surface of a sunbathing Weddell seal was acting as a radiator—which explained the seal-shape tubs that had melted into the ice. By comparison, when I pointed our camera at Rutishauser, who was bundled in a parka and insulated wind pants, his thermal image was blue and nearly invisible against the blue backdrop of the ice.

Here again, in whole-body cooling, we found that specialized blood vessels were the mechanism for transporting heat and controlling temperature in the seals. Hair follicles throughout the pelt of a Weddell seal occur with a side-by-side array of highly branched arteries and veins known as arteriovenous anastomoses (AVAs). More than 6,000 AVAs are packed into every square inch of the seal's skin, where they act as thermal perforations along the pelt, enabling excess heat to escape when the seals lie in the Sun.



Poking its head through a hole in the ice, a Weddell seal (top) enjoys a long-awaited chance to breathe. While lying on the surface of the water, another seal (bottom) keeps the icy waters out by squeezing its muscular nose shut. A network of blood vessels surrounds the eyes to keep them from freezing, and so they glow with heat in the thermal image.

The distribution of the AVAs for Weddell seals was originally described in 1975 by G. S. Molyneux and M. M. Bryden of the University of Queensland in Brisbane, Australia. But seal AVAs differ in shape, complexity, density, and distribution from the AVAs in terrestrial mammals. The AVAs of sheep and rabbits, for instance, also regulate temperature, but they are densest in sparsely furred peripheral areas such as the forelimbs and ears. The density of AVAs in Weddell seal skin is several times greater than it is in such land-based mammals, and their distribution is bodywide. With the infrared camera we could observe the sequential opening of the AVAs along the body and the consequent warming of the sunbathing seals' skin. Slowly the seals turned from a cool blue to a bright warm orange, as blood flowed through the AVAs.

Weddell adults and pups alike have AVAs, but their function changes as the pups mature. Newborn Weddell seals lack a substantial blubber layer, and so they rely instead on a pajama-like coat of fluffy gray hair called lanugo to retain body heat. Because the ratio of the surface area to the volume of their small bodies is relatively high, they cool quickly. As a result, they have to be particularly careful to conserve body heat. In our infrared images the youngest seals resembled Matt in his parka, showing blue rather than the red of their parents. The AVAs hidden beneath the lanugo appeared to be closed.

As they grow fatter from nursing, the pups lose their lanugo, add blubber, and acquire the sleek spotted coats of the adults. But with a new coat and a thick blubber layer for insulation, the pups now face the same dilemma as the adults, how to get rid of excess heat. Soon the flippers of the pups are glowing warm, and by the time they are six weeks old, their entire body is as red-hot as their sunbathing mothers.

Even as young pups, then, Weddell seals have several anatomical adaptations that enable them to avoid overheating in the sunlight. But why did they ever need them in the first place? After all, wouldn't it be far simpler for them to stay in the water, where it is cool enough to let blubber take care of their thermal needs? Several behaviors we observed offered one explanation.

Anyone watching the sunbathing Weddells quickly notices that many of them have numerous skin wounds. Flippers, armpits, backs, and bellies are often covered with bites; some are large, open, and bleeding, but most are just small nicks and scrapes. With a submersible camera developed by Randall W. Davis, a physiologist at Texas A&M University in Galveston, our team was able to observe the underwater behavior of the seals, and soon discovered how the wounds come about.

After a dive in search of a meal, seals frequently

Breathing holes in the ice are small and scarce. When a seal returns to breathe after a long, deep dive, it may bite any other seal blocking the way to the air. Such bites have little chance to heal underwater, but the warm Sun may promote healing. Hence sunbathing may be the seals' indirect response to the scarcity of breathing holes.

battle each other for access to breathing holes in the ice. The fights become more intense as temperatures fall and ice holes and cracks freeze shut. It is not unusual for a seal returning from a prolonged dive to resort to a quick nip on the flippers or belly of another seal in order to gain access to a breathing hole. When the animals we observed hauled themselves up onto the ice, the infrared camera readily highlighted the battle scars. In one case a male seal was so badly bitten that he looked as spotted as a Dalmatian dog, with red, hot wounds covering his entire body [*see lower photograph on page 52*].

So perhaps the sunbathing behavior of the Weddell seals is not simply a recreational activity but, rather, integral to the healing of their many wounds. In mammals, tissue repair requires the development of a large number of blood vessels and subsequent heating of the injured area. That component of healing has recently been the focus of intense medical research. Heated bandages, radiant-heat dressings, and even laser therapy are all under investigation to promote tissue repair in human patients. It occurred to me, as I watched the battle-scarred seals lying in the Sun, that the sunbathing Weddells of the Antarctic had already discovered the benefits of radiant-heat therapy. By hauling out in the constant sunlight, blood—and so heat and oxygen—flows to the injured areas. That promotes healing. As the ghostly blue infrared images of submersed seals had shown, the alternative is poor blood flow to the cool skin, and presumably little chance for wounds to heal.

But whatever their reasons, Weddell seals young and old are drawn to one of the southernmost sunbathing beaches on Earth. During the long days of the Antarctic summer they sleep and yawn, scratching their heads and bellies, their idleness in stark contrast to the lively activity of the remarkable thermal mechanisms operating just below the skin.

By late April the Sun has sunk below the Royal Society mountain range for the last time, drawing the animals and their icy beach into total darkness for several months. It is hard to imagine how the Weddell seals stay warm and nurse their wounds during those long, cold, winter nights. The severity of the Antarctic winter will keep that secret hidden with the seals for now. □

Fern Relations

A patch of forest in Massachusetts harbors some shady characters.

By Robert H. Mohlenbrock

Bartholomew's Cobble, looking northward, with the Berkshires in the distance

Near the foot of the Berkshire Hills, alongside the scenic Housatonic River in southwestern Massachusetts, is a National Natural Landmark known as Bartholomew's Cobble. In its 329 acres more than 800 plant species flourish, including fifty-three species of ferns and so-called fern allies, one of the finest such concentrations in the United States. The "Cobble" part of the site's name refers to two large, adjacent outcroppings of bedrock (think "cobblestone"). Bartholomew is the name of a family that farmed the land from 1833 until 1901. The Trustees of Reservations, a Massachusetts land trust that now owns the property, acquired the main parcel in 1946 and added to it in subsequent years through purchases and donations.

About 70 percent of the landmark area is covered in forest dominated by hemlock. Where the shade is not too dense, the forest floor is brightened by a number of flowers, especially in springtime; in autumn, broadleaved trees such as northern red oak and sugar maple stand out amid the evergreens, adding splashes of blazing red and orange. Portions of the rock outcroppings are also forested with hemlocks or other trees, and many plants find a foothold in the crevices of the exposed bedrock. Only the west-facing areas of the limestone, marble, and quartz, which get the brunt of the afternoon sunshine, remain dry and nearly bare of vegetation.

Found in the shade throughout the growing season are numerous ferns and fern allies. All of them are vascular plants that do not form seeds as part of their reproductive cycle. Like many plants, their generations alternate between a spore-producing form, called the sporophyte, and a gamete-producing form, called the gametophyte. In vascular plants, the sporophyte is the plant people usually see and recognize. It gives rise to spores, which are haploid cells—cells that contain only one from each pair of chromosomes in the parent plant. The dispersed spores grow into gametophytes, small and obscure structures that give rise to gametes, or sex cells. When two gametes unite—restoring the double number of chromosomes—the resulting cell can give rise to a new sporophyte. (A seed is merely a dormant, embryonic sporophyte, protected by a covering and supplied with a store of food; dispersed in this form, the sporophyte can germinate and grow rapidly when conditions are right.)

Ferns, whose sporophytes usually have delicate-looking, much divided, broad, flat leaves, are common denizens of the forest. About forty-five species grow at Batholomew's Cobble. Fern allies tend to be less familiar. They often differ from ferns in the appearance of their sporophytes but are defined botanically according to various details of their gametophyte life cycle, which is more complicated than that in ferns.

Fern allies fall into five families, three of which are represented in the landmark area. One of these is the Equisetaceae, members of which are often referred to as living fossils: the group dominated terrestrial plant life when dinosaurs roamed the Earth. Their sporophyte has a jointed, leafless stem containing silica, which the plant takes up from the soil. If the stem is unbranched, the species is aptly (but not always) called a scouring rush (American pioneers would bind bunches of the stems together and use them to scour pots and pans). If whorls of very slender branches radiate from each joint, making for a bushy-looking plant, it is more appropriately referred to as a horsetail.

Two more families of fern allies found in Bartholomew's Cobble are the club mosses (Lycopodiaceae) and spike mosses (Selaginellaceae). Both

tend to have small leaves that are flat or scalelike. Club mosses with stiff branches and scalelike leaves are often called ground pines.

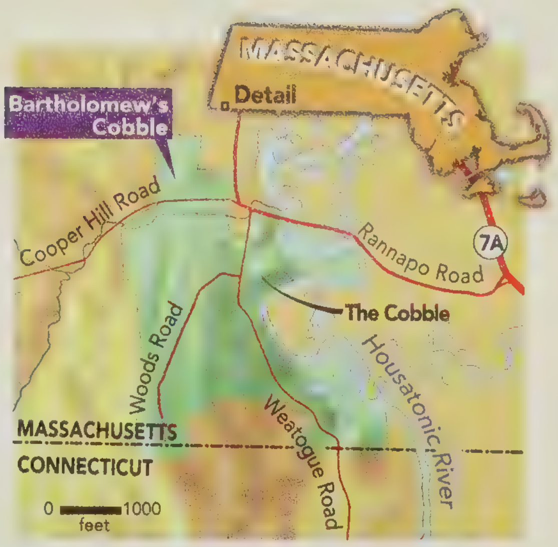
HABITATS

Hemlock forest American beech, basswood, northern red oak, sugar maple, and white pine, along with the hemlock trees, create a deep shade. In it grow such ferns as adder's-tongue fern, bog fern, Christmas fern, crested fern, Goldie's fern, maidenhair fern, New York fern, ostrich fern, and spinulose woodfern. The delicately branched woodland horsetail and two ground pines (fan club moss and running club moss) also grow here. Where the woods border the Housatonic River appear colonies of large cinnamon fern, ostrich fern, and royal fern, along with the somewhat smaller sensitive fern. Joining these are three scouring rushes (common scouring rush, variegated scouring rush, and water horsetail) and the common, or field, horsetail.

Wildflowers that grow beneath the canopy include so-called spring ephemerals—plants that usually come up in early April, bloom no later than the end of May, set seeds in May or June, and disappear by July. Among them are Dutchman's-breeches, spring-beauty, and various species of toothwort, trillium, and violet. A few spring wildflowers persist, such as doll's-eyes, Solomon's seal, and false Solomon's seal. Nonephemerals that bloom during the summer or fall are Canada lily, false hellebore, and species of aster, goldenrod, and sunflower.

Moist rock Ferns that grow from very moist, moss-covered patches of soil on the rock outcroppings include berry bladder fern and brittle bladder fern (also called fragile fern), both of which, in addition to forming spores, create asexual "bladders"—small bits of tissue that can grow into a new plant if they land in a favorable place. Others are maidenhair spleenwort, two kinds of polypody, and walking fern. Walking fern is unfernlike in appearance because it has undivided, narrow, lance-shaped leaves that taper to a long, drawn-out tip. Where the point of the leaf touches the mossy substrate, the tip forms roots, anchoring the plant on the rock face. In this manner, the fern "walks" across the rocky surface. The delicate spring meadow spike moss, with nearly transparent leaves, lies flat on moist, mossy surfaces at the base of some of the rocks.

Exposed rock Crevices in drier bedrock harbor such ferns as purple cliff-brake and two species of *Woodsia*. Also found here is shining club moss, which has membrane-like leaves and spore cases hidden at the base of each leaf, and the spike moss northern selaginella, which has short, needlelike, evergreen leaves. Another cliff-dwelling plant is yellow honeysuckle, whose downward arching stems bear flowers from June through August. Wildflowers include bishop's-cap, blue-stem goldenrod, buffalo currant, hepatica, herb Robert, wild columbine, and zigzag goldenrod.



For visitor information, contact:
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Running club moss, a "fern ally" and one of several club mosses also commonly known as ground pines, produces its spores in elongated cones.

Walking fern—which looks nothing like a typical fern—spreads by growing new plants at the tips of its long, slender leaves.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

Dorothea Lange, *Tractored Out,* Childress County, Texas, 1938

Crop Circles

Spin notwithstanding, can GM food still save the world?

By Marc J. Cohen

What good is genetically modified food? Is GM food a savior, an essential ingredient in any program for ending world hunger? Or is it a villain, a Trojan horse that, if allowed into the food production and distribution system, will poison people and the environment? Few aspects of everyday life provoke such sharp disagreement as the emerging biotechnology of food.

Yet there is remarkably broad consensus that there is a crisis in world hunger and about the reasons for it. Almost everyone who has looked seriously at the causes of hunger agrees that the main factor is poverty. People go hungry because they lack money to buy food, or they lack the land, water, credit, and other resources they need to produce food on their own. Poverty, in its turn, is often linked to political powerlessness, gender discrimination, poor education, and the debilitation resulting from endemic, untreated disease. Each year malnutrition in developing countries contributes to the deaths of more than 5 million preschool-age children—a toll equivalent to the entire population of Denmark. The malnourished children who survive face a lifetime of impaired physical and mental development.

Yet global food production is rife with paradox. Enough food is available today to provide every human being on Earth with more than the 2,350 calories needed daily for a healthy and active life. Even more paradoxical than the persistence of hunger amid plenty is that its center of gravity occurs in rural areas. Some 75 percent of those with inadequate access to food live in the countryside of the developing world. It is here, in such areas of rural poverty, that new agricultural technology, in particular biotechnology, may offer the greatest hope for improvement.

Unfortunately, that hope remains largely unrealized. Biotechnological developments have led, however, to a bumper crop of books aimed at popular audiences. Two of the latest additions are *Food, Inc.: Mendel to Monsanto—The Promises and Perils of the Biotech Harvest,* by the journalist Peter Pringle, and *Safe Food: Bacteria, Biotechnology, and Bioterrorism,* by the nutritionist Marion Nestle.

In many ways biotechnology would seem made-to-order to address part of the plight of small farmers in developing countries. Agricultural productivity there remains low, which implies both high unit costs of producing food and low farm incomes. Many factors contribute to the low productivity: losses to pests and the weather; low soil fertility and lack of access to fertilizers; acid, salinated, or waterlogged soils. The low yields that result lead in turn to poor nutrition and poverty on the farms, as well as among the people who depend on such farms for food. As the circle of poverty widens, demand for goods and services produced by poor nonagricultural rural households decreases, and urban areas suffer increased rates of unemployment and underemployment.

Food, Inc.: Mendel to Monsanto—The Promises and Perils of the Biotech Harvest
by Peter Pringle
Simon & Schuster, 2003; $24.00

Safe Food: Bacteria, Biotechnology, and Bioterrorism
by Marion Nestle
University of California Press, 2003; $27.50

Agricultural technology alone cannot address all the complex economic, social, political, and ecological forces that contribute to world hunger. And technology cannot reach its potential unless it is part of a comprehensive strategy to reduce poverty, enfranchise low-income people, and protect the environment. Still, research that leads to increased productivity can play an important role in reducing hunger. For example, crops could be designed to resist drought, pests, and diseases; tolerate salty soil; absorb nitrogen from the air; and provide a broad range of added nutritional benefits.

But the potential of biotechnology for helping reduce hunger has barely been tapped. Virtually all the biotech crops currently on the market are limited to just two traits: herbicide tolerance and insect resistance. A big share of the global GM harvest for 2002—two-thirds of which was in the hands of U.S. farmers—went into animal feed or textile fibers. Commercial soybean farmers in Argentina, whose operations have much more in common with North American large-scale farms than with African subsistence plots, accounted for another big chunk of the GM harvest. Small farmers in China, India, and South Africa have begun to grow pest-resistant GM cotton.

Back before anyone had heard of GM foods, the great advance in food production technology was the introduction of high-yield seeds, the so-called Green Revolution, which reached its pinnacle in the the late 1970s and early 1980s. The new seeds boosted global cereal output, though their use was generally accompanied by increasing application of mineral fertilizers, synthetic pesticides, and irrigation water.

There are two big differences, though, between the Green Revolution and its modern counterpart. The research and development for the Green Revolution were carried out almost entirely by public-sector research institutions and philanthropic foundations. Public policies, moreover, played a central role in encouraging the adoption of the technology. The fruits of the research were placed in the public domain.

In contrast, the vast majority of the research in agricultural biotechnology that is the basis for the Gene Revolution (as many have come to call it) has been carried out in the laboratories of private multinational "life sciences" corporations, based in the industrialized nations. Having made huge investments, the corporations are eager for profits to recoup their costs. Accordingly, they seek patents or other forms of intellectual-property protection for both the products and the processes they develop.

The second big difference between the Green and Gene revolutions is that the former was based on conventional crossbreeding among different varieties of a single food-crop species, or, occasionally, a crossing with close relatives. But the Gene Revolution, with the development of recombinant DNA technology, made it possible to transfer genes between species, even between plants, animals, and microorganisms. Biotechnologists have inserted a gene from a soil bacterium into corn and cotton, enabling the plants to produce their own natural insecticide. Rice containing genes from daffodils and bacteria—labeled GoldenRice because of its yellow tint—may soon be available to farmers; it is high in beta carotene, which the body converts to vitamin A. In developing countries, inadequate vitamin A leads to infectious diseases, blindness, and death for hundreds of thousands of children each year.

The two volumes under review address food biotechnology from quite different points of view. Peter

Pringle stakes out a middle ground in a highly polarized debate, and explores how the technology might become more accessible to poor farmers in developing countries, particularly in Africa. Marion Nestle devotes only about half of her book to biotechnology (the rest deals with food safety in more traditional contexts), and she focuses her discussion of biotechnology on the resistance by the food industry to stronger, more coherent government safety regulations. In passing, she, too, addresses the potential relevance of food biotechnology to poor farmers and consumers in developing countries, but her focus is mainly on the United States.

Pringle's book is organized around the flash points of food biotechnology, the stories that have gotten major media attention in the past few years: the development of GoldenRice; reports that GM crops are harmful to monarch butterflies; laboratory experiments on mice that raised concerns about health risks; and the discovery of GM corn pollen in Mexico, leading to accusations that it could contaminate natural strains.

William H. Martin, *Riding a Giant Corncob to Market,* 1908

Pringle takes a balanced approach to his topic, criticizing both the extreme claims of biotech companies, which trumpet their seeds as the salvation of the starving, and the "environmental ideologues" who cry "Frankenfood!" and seek to ban biotechnology altogether. He rebukes the London-based environmental group Greenpeace for its willingness to seize on any evidence of environmental or health risk, however inconclusive, to support calls for a ban and to justify the destruction of test plots. At the same time, he condemns executives of the Monsanto Company, based in St. Louis, Missouri, the leading purveyor of biotech seeds, for their "arrogance." For example, he cites their unwillingness to concede that pollen from GM crops could cross-fertilize nearby conventional or organic varieties. (An organic grower whose crops become cross-pollinated could lose hard-won and lucrative organic certification.)

Pringle also notes a much more troubling effect that GM food is having on the tangled politics of world hunger. European consumers continue to voice fierce opposition to GM foods, and the European Union is seeking to impose strict labeling requirements on GM products. Consequently, the leaders of some developing countries are reluctant to adopt GM food technology, or even accept food aid that might contain biotech seeds. Either action, they fear, might compromise their nation's ability to export food products to Europe. An extreme case unfolded last year, when famine-stricken Zambia rejected U.S. food aid on just such grounds.

In Pringle's view, though, GM foods are here to stay. More caution will be needed in developing and deploying them; genuine risks will have to be properly managed. But, with those caveats, he thinks the technology may help reduce hunger. To do so, industry will have to be more willing to make patented technology available to developing countries. Governments of developing countries will need to devote a greater share of their expenditures to agricultural research. And seed banks must receive adequate funding for operations and maintenance to conserve plant genetic diversity.

Among the strengths of *Food, Inc.* are its clear explanations of the complex science of plant biotechnology, as well as the complex history of how U.S. patent law has evolved to cover novel plants and even genes. Unfortunately, though, Pringle ignores the important precedent set by India's 2001 seed law, which seeks to balance plant breeders' rights to profit from their innovations with farmers' rights to use the seed they harvest from the plants they grow. That model has great bearing on how biotechnology might benefit poor farmers.

Where Pringle is evenhanded in showing how extremists have hijacked the debate over GM food, Nestle is an unapologetic partisan. As she writes in her introduction, a major theme of her book is "the food industry's promotion of economic self-interest at the expense of public health and safety." In the case of food biotechnology, she maintains, the industry invokes "science" as a cover for advancing its own interests.

As Nestle shows, U.S. government regulators who are supposed to ensure that foods do not threaten public health or the environment often bend over backward to accommodate industry. In part, that cozy relationship is a consequence of the "revolving door" that moves key people back and forth between industry and government. Another difficulty is that regulatory authority is fragmented across a bewildering spectrum of government agencies and limited by long-outdated statutes. As Nestle notes, Congress can change the laws, but generous campaign contributions from industry ensure a favorable legislative environment.

For Pringle, adequately funded public science would be a saving grace, but Nestle is skeptical. The department of

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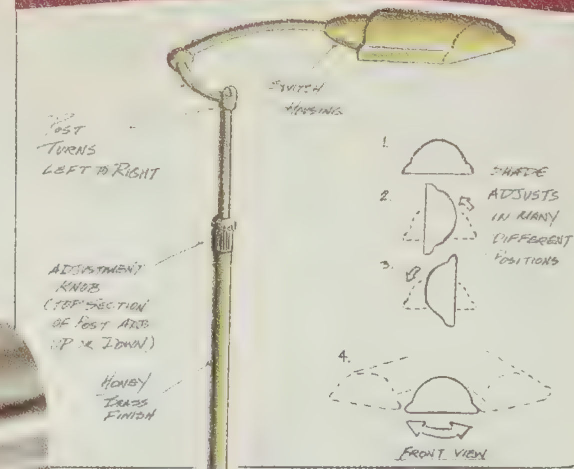

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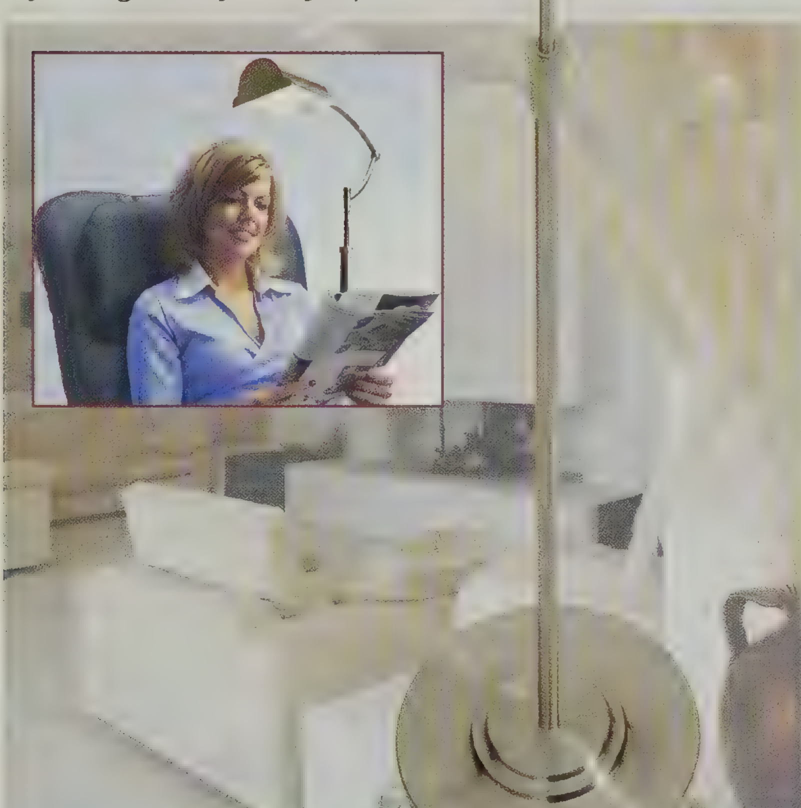

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plant and microbial biology at her alma mater, she writes, the public University of California, Berkeley, "auctioned itself" to the Swiss biotechnology firm Novartis International AG, headquartered in Basel. The arrangement, she states, allowed the company to review research prior to publication and to negotiate licenses.

The case of GoldenRice, engineered by Ingo Potrykus, a plant biologist at the Swiss Federal Institute of Technology in Zurich, highlights some of the pitfalls now faced even by scientists at public institutions, funded through philanthropic foundations, who get caught in the intricate web of corporate patents. Pringle shows how the development of GoldenRice, which at first seemed a triumph in the war against malnutrition, turned into a nightmare snarl of ownership claims covering dozens of processes and genes. He points out that the public-sector scientists were hardly to blame for their partnership with the private sector: the European Commission required them to partner with a European company in order to get public funds. The company then obtained the exclusive right to market GoldenRice in the industrialized world, in exchange for making it available free of charge to poor farmers in developing countries.

Nestle is much more sympathetic than Pringle is to the critics of food biotechnology. She argues that they have couched their criticisms in the language of food safety, particularly in the United States, because regulatory policy has limited debate strictly to scientific questions. Social and political issues—the concentrated corporate control over biotechnology, the lack of transparency in decision making, the corporate resistance to food labeling that could make consumers better-informed about their choices—are not on the scientific agenda. Thus, Nestle maintains, critics have no choice but to demonstrate, litigate, and, on occasion, engage in provocative rhetoric, often disseminated quite effectively via the Internet. (Despite her sympathies, however, Nestle, like Pringle, condemns acts of violence that opponents of biotech have sometimes directed against test plots and laboratories.)

Nestle devotes a lot of attention to the globalization of food safety and biotechnology. She rightly points out that food-safety standards in industrialized nations are often little more than tariff barriers by another name: they protect domestic growers by keeping out competing agricultural products from developing countries. She also explains how the debate about labeling has gone global: the European Union, for instance, is seeking to have biotech imports separated from conventional produce, and documented as to their source.

One department at UC Berkeley, Nestle writes, "auctioned itself" to a Swiss biotechnology firm.

But Nestle's presentation is marred by errors and omissions. She does not discuss the formal U.S. complaint to the World Trade Organization—which she repeatedly and incorrectly refers to as a UN agency—that the Europeans are violating global commercial rules by discriminating against GM products. She also writes that an international agreement called the Biosafety Protocol permits countries to ban GM food imports because of concerns about environmental safety, but she fails to mention that the U.S. government vociferously rejects that interpretation.

Like Pringle, however, Nestle does not reject food biotechnology outright. She, too, regards it as a tool for alleviating hunger—despite her criticism of corporate tactics. She calls upon the industry to "tithe," donating 10 percent of its profits to research into the food needs of developing countries.

One encouraging model may be the way a GM sweet potato was developed in Kenya. A crippling infection known as the feathery mottle virus can reduce sweet potato yields by 80 percent. In Kenya, sweet potatoes are grown mainly by poor farmers and eaten by poor consumers, so the economic implications of creating a disease-resistant GM sweet potato had little in common with, say, the adoption of herbicide-tolerant soybeans in North America. In particular, biotechnology corporations did not stand to profit significantly from such a project. Accordingly, Monsanto licensed its technology free of charge to a publicly funded institution, the Kenyan Agricultural Research Institute. That enabled Kenyan investigators to engineer a sweet potato that resists the feathery mottle virus. Critics have called Monsanto's contribution a public-relations move. But if such free licensing in developing countries were more the norm, such criticism would carry less weight, and more research relevant to hunger would be done.

Food production, of course, is just one piece in the hunger puzzle, and biotechnology is only one part of food production. For example, people must also have access to the food produced—yet more than 800 million people, one in seven worldwide, do not have ready access to all the food they need. According to the UN Office for Coordination of Humanitarian Affairs, that figure includes 56 million people (more than two-thirds of them living in sub-Saharan Africa) who need food and other emergency humanitarian assistance.

Those figures actually represent an improvement since 1970. Three decades ago more people went hungry, both in absolute terms (an estimated 959 million) and as a fraction of the world population (more than one in every four people). But the

rate of progress in reducing hunger slowed in the 1990s, compared with the two preceding decades. Leaving aside China (where the number of the hungry was reduced by 74 million), the number of hungry people in the rest of the developing world actually rose by 50 million during the 1990s. Hunger is increasingly concentrated in South Asia and sub-Saharan Africa, and in the latter region the number of people lacking access to adequate food more than doubled between 1970 and 1999.

Access to food is hampered by poorly developed markets, environmental degradation, inadequate roads, isolationist regimes, theft, and any number of other factors. The social consequences of such failures to feed hungry populations include huge stresses on already overtaxed medical systems, reduced productivity, stunted economic growth (compounding the poverty), and malnourished mothers who give birth to more malnourished children. Vitamin and mineral deficiencies, which afflict more than 2 billion people, likewise lead to illness, lost productivity, premature death, and less prosperous economies. Political instability, violence, and hunger go hand-in-hand.

One common misconception is that many people still die from outright starvation, or "famine." In fact, famine per se directly kills perhaps no more than 200,000 people a year, on average. But the consequences of hunger, malnutrition, and related disease account for nearly 11 million deaths a year, a fifth of the deaths from all causes globally. The scope and complexity of the problem of hunger will unfortunately continue to call on the best minds and noblest hearts among us for a long time to come.

Marc J. Cohen is Special Assistant to the Director General of the International Food Policy Research Institute, a publicly funded international agricultural research center that identifies and analyzes strategies for improving the food situation in developing countries (www.ifpri.org).

BOOKSHELF

By Laurence A. Marschall

Space, the Final Frontier?
by Giancarlo Genta and Michael Rycroft
Cambridge University Press, 2003; $29.00

Edward H. White took the first U.S. spacewalk, June 3, 1965.

Rockets, like locomotives almost two centuries ago, are embodiments of progress, symbols of society's technical mastery over nature, and so they raise a host of questions about the ultimate destiny of the human race. Most people seem to take one of two general points of view on the quest that rockets represent: A vocal minority is certain that humanity will colonize space, just as Europeans colonized the New World. A less vociferous majority doesn't seem to have given the subject much thought. As a result, the debate, if it can be called that, tends to be rather lopsided.

Space enthusiasts, who write most of the science and science fiction on the subject, take it for granted that, given enough time, humanity will spread throughout the galaxy. To them, the outstanding questions are largely technical: Is it easier to mine metals from the asteroids on-site, or is it more economical to tow them first to the Moon? Can a nuclear-powered rocket carry enough fuel to make it to the nearest star and back again? How can the human body and psyche be prepared to survive long journeys in space?

Those questions, however, don't interest most people. Opponents of the space program have long pointed out that too many pressing problems remain on Earth to give serious attention to technologies so far away, both in space and time.

The question mark in the title of *Space, the Final Frontier?* might have signaled a third point of view—a critique of the very idea of a cosmic manifest destiny. But Giancarlo Genta and Michael Rycroft fail to deliver much beyond a few "on the other hand" comments. That's a shame, because their book serendipitously appears at a critical moment in the space debate, and their discussions might have informed the questions raised in the recent report on the breakup of the space shuttle *Columbia*. The authors of that report excoriated policy makers for the budget cuts and drift of purpose that, according to their investigation, were partly responsible for the deaths of seven astronauts this past February. In effect, they told the government, give NASA a compelling mission for sending people into space—and then fund it appropriately—or else get out of the manned space business.

For the most part Genta and Rycroft are strong on the mission but weak on the analysis of cost, writing optimistically about colonies on the Moon, manned expeditions to Mars, and eventual colonization of the stars. Sympathetic space enthusiasts will enjoy the compendious coverage of topics ranging from the prospect of "terraforming" other planets into carbon copies of Earth, to methods for traveling faster than the speed of light (well, maybe).

How much of what Genta and Rycroft describe is wishful thinking? They do offer an occasional cautionary remark about the physical, economic, and ethical limitations on placing people in outer space. And they hedge their bets by avoiding specific predictions for how long it will

take to colonize this or that planet, or to travel to this or that star. But they leave no doubt that human destiny lies in the heavens. The clear implication is that those with reservations about the enterprise are, alas, quixotically trying to hold back the tides.

Some of their argument is utilitarian: just as the Western frontier provided *lebensraum* for the surplus population of nineteenth-century America, so space will provide a safety valve for a planet threatened by pollution and overpopulation. And the arguments put forth by some for a "space imperative," the authors say, are even more important: "space exploration is a primary duty of humankind, who must not let themselves always be distracted by problems, even by the very serious ones."

Exhortations aside, what if there is a fundamental difference between the terrestrial frontiers of the fifteenth through the twentieth centuries and the frontier of space? Consider that undersea travel has been possible for more than a century. Yet though the ocean bottom is far closer than the Moon, it remains a place visited only temporarily, by expensive oceanographic and military vessels. How many permanent colonies will be established in the foothills of the mid-Atlantic ridge? How many undersea mines, mills, and Wal-Marts will be built there? Is it just a lack of will that keeps our feet on terra firma? Or are the barriers between the heavens and the Earth much higher than even a pair of rocket scientists can imagine?

Eating Apes
by Dale Peterson, with an afterword and photographs by Karl Ammann
University of California Press, 2003; $24.95

Karl Ammann, in love with Africa from an early age, is a Swiss citizen who has lived for the past quarter century in Kenya. He came to Nairobi as a hotel manager and gradually drifted into wildlife photography. But his experience aboard a huge trading and transport vessel during a business trip on the Zaire River more than a decade ago turned him abruptly from hotelier into environmental activist. The issue was the trade in wild game, or, as Africans call it, bushmeat.

Ammann had noshed on bits of python in the past, but he had never appreciated the enormous dimensions of the bushmeat market, or how many species find their way to African tables. As the vessel sailed upriver, hunters paddled out from shore, offering carcasses as well as live animals to the crew and to the professional meat merchants onboard. The boat's meat locker became crammed with freshly

Chimpanzee, illustration from a 1686 volume by the Dutch geographer Olfert Dapper

slaughtered lizards, monkeys, snakes, and turtles. Live crocodiles, hogtied to keep them fresh for market, began to pile up on the decks outside the merchants' cabins. Then one day a hunter carrying a cheap shoulder bag came on board with the smoked carcass of a mother chimpanzee; inside the bag was the chimpanzee's orphaned baby.

Ammann bought the baby, and in the months that followed he searched among the various African primate refuges to find it a home. The experience transformed him into a fierce advocate for change in African hunting practice and diets. In the past decade he has gone "underground" in several countries to report on the illegal market in apes and other large mammals. His stark color photographs of slaughtered gorillas and chimpanzees (some of which are reproduced in this book), have energized a growing public awareness of the need for more effective regulation of the bushmeat trade.

Dale Peterson, who has written widely about primates in Africa, makes Ammann's story the centerpiece of his wide-ranging account of the bushmeat problem. Although he shares Ammann's partisan views, Peterson explains why conservationists cannot simply will the end of ape-eating through legislation. Selling ape meat is already illegal throughout most of Africa. But so many people rely on bushmeat for protein, and so many regard it as a delicacy that connects them with their past and their ethnic identity, that game wardens and police officers are more likely to buy bushmeat from a poacher than to arrest him.

Peterson shows, too, how European logging corporations in Central Africa are playing a key supporting role in the growth of the bushmeat trade. They cut roads deep into virgin forest, giving hunters ready access to once-remote habitats. They cut costs by feeding cheap bushmeat to the loggers. And the truck drivers they employ run a lucrative side business in the transport of contraband ape body parts, concealed in compartments under their engine hoods. The net effect is that hunting bonobos, chimpanzees, and gorillas has now become big business. And the targeted species, already endangered, may be driven to extinction.

With such strong economic and social forces in play, any argument that simply appeals to the repugnancy of eating our closest cousins is bound to be dismissed as ethnocentrism. If the French eat horses, or the Vietnamese eat poodles, who's to say the Africans can't eat apes? Peterson counters that eating apes endangers public health. He cites the work of Beatrice H. Hahn, a virologist at the University of Alabama in Birmingham, who in 1998 traced the AIDS virus to a virus known as SIV, common among chimpanzees. This past June, Hahn and her colleagues reported in the

journal *Science* that the chimpanzees themselves may have contracted the virus by eating monkeys.

Unlike chimpanzees, though, people can clean up their act. If advocates like Peterson and Ammann prevail, apes may someday disappear from the market and the dinner table. With any luck, that will happen before they disappear from the rainforest as well.

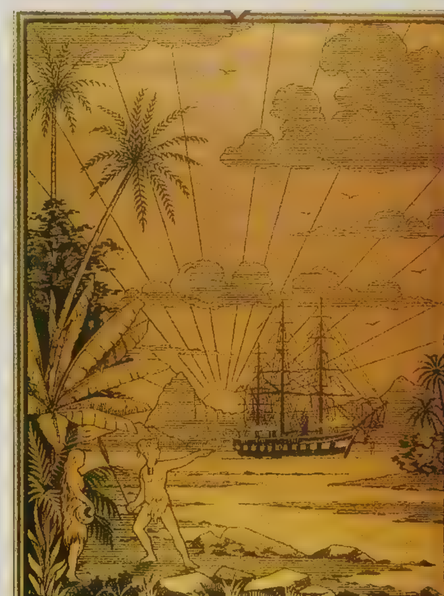
The Silent Landscape: The Scientific Voyage of HMS Challenger
by Richard Corfield
Joseph Henry Press, 2003; $24.95

The nineteenth century, no less than the age of Columbus and Magellan, is notable for its voyages of exploration. A search of Amazon.com returned nearly thirty entries for books about Darwin's travels with the HMS *Beagle,* and more than twenty for books about John Franklin's ill-fated expedition to the Arctic. Yet only two entries (one for this book!) featured the HMS *Challenger,* which carried out the most remarkable and influential maritime mission of the Victorian era. The obscurity of *Challenger*'s voyage is understandable: no lands were claimed, no passage remained blocked by ice, no crews were decimated by frostbite, scurvy, or starvation. In fact, the voyage went pretty much as planned—which is to say it brought back scientific results of surpassing importance.

HMS *Challenger* left Portsmouth, England, in December 1872 with an itinerary that had been drawn up, not by commercial explorers or adventure-seekers, but by the academicians of the British Royal Society. Its objectives were scientific, pure and simple: to circumnavigate the globe, to take soundings at regular intervals along the way, and to measure the physical and biological characteristics of the ocean, from surface to bottom. Aboard were twenty naval officers, a crew of 200, and a scientific staff of five. John Murray, one of the scientists, spent the remaining decades of the century compiling a fifty-volume report on the expedition's results. *Challenger* was the first great oceanographic research vessel, and its findings were to set in motion revolutions in earth science and biology for the next hundred years.

When *Challenger* set sail, the prevailing wisdom was that ocean life could not exist below about 300 fathoms (1,800 feet). Yet virtually every time the dredge was hauled up from the deep, so many weird creatures came to light that scientists and crew alike quickly conceded that the ocean depths are a rich repository of primitive life-forms.

By the time the ship had reached the West Indies, the expedition scientists had come upon a great range of undersea mountains running down the middle of the Atlantic Ocean. Two years later, on the other side of the world, their sounding lines revealed a chasm in the western Pacific more than five miles deep. Both features, and many others first recorded by *Challenger*'s crew, are now recognized as part of the system of cracks and seams that connect the moving tectonic plates of our planet's crust.



HMS Challenger, from the frontispiece of the 1878 volume At Anchor

Richard Corfield draws not only on the voluminous records of the expedi-

EXPLORER GUIDE

[illegible] but also on the per[illegible] memoirs of its naval officers—[illegible] memorably, the candid and pre[illegible]usly unpublished diary of a young ship's steward named Joseph Matkin. The book's real excitement, though, lies in the many technical digressions that Corfield, an earth scientist himself, includes from the perspective of modern science. Climatology, evolutionary biology, oceanography, and plate tectonics all got a jump start from *Challenger's* results. It's easy to understand why two great contemporary research vessels—the *Glomar Challenger,* the first oceanographic drilling vessel, and the late and much lamented space shuttle *Challenger*—both bore the name of a cramped and creaky sailing ship of a century gone by.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

nature.net

Thought for Food

By Robert Anderson

Unless you don't eat, you probably already have strong personal opinions about genetically modified (GM) foods [*see "Crop Circles," by Marc J. Cohen, page 58*]. Rightly or wrongly, they call forth many of the same health anxieties people have about pesticides, hormones, and food irradiation.

A good place to begin sorting through the relevant information available on the Internet is the "GM Food" page at "Scope" (scope.educ.washington.edu/gmfood/). On the "Scope Forum" menu, at the upper left of the screen, "Positions" will lead you to incisive responses from eight experts to questions about the risks and benefits of GM foods. "Site Bites," in the same menu, gives brief reviews of sixteen other Web sites on GM food, "scoping out" the biases you're likely to run into at each one.

I began with the site run by the Union of Concerned Scientists. Their "Food" page (www.ucsusa.org/food_and_environment/index.cfm) offers a balanced examination of humanity's short experience with GM crops (click on "Biotechnology" under "In This Section"). Under "Contents," on the right, you can also click on two excellent "Special Features" that focus on the way new technologies can threaten the food supply. A good discussion of the risks of genetic engineering is available under "Backgrounders," and under "Guides" you'll find a list of altered foods currently allowed in U.S. markets.

To check out one of the principal players on the "upbeat" side of the debate, the "Site Bites" reviews suggest Monsanto, which has "created an unceasingly and completely positive picture of GMFs" (go to www.monsanto.com/ and search for "GM Food"). So has the U.S. Department of Agriculture (www.usda.gov/agencies/biotech/index.html): "Blue skies for agricultural biotechnology, here," says the Scope review.

But to see how a bastion of spirited scientific nay-sayers is saying nay, go to the "Genetic Modification" page of the London-based Independent Science Panel (indsp.org/gm.php). There you'll find the organization's recently issued report, "The Case for a GM-free Sustainable World."

If you're looking instead for some explanation of biotechnology that falls in between the Bad Guys and the Good Guys, Colorado State University offers an up-to-date guide to transgenic crops. Without taking sides, this excellent site (www.colostate.edu/programs/lifesciences/TransgenicCrops/index.html) presents the science underlying the issues in substantial detail. On the menu at the left, the entries on current and future transgenic products (toward the bottom of the list) give concise overviews of specific GM crops in use and in the pipeline.

Whether or not you think the trend toward GM foods is leading into dangerous waters, you do have the right to know which of your supermarket purchases have been genetically engineered. GM-food labeling is not required yet in the United States, but some of the more partisan Internet sites can help you out. For example, at Greenpeace's "True Food Network" site (www.truefoodnow.org/) you can click on the blue icon at the right for the "True Food Shopping List." There you'll see which companies have embraced the brave new world and which continue to make food the old-fashioned way.

Robert Anderson is a freelance science writer living in Los Angeles.

(Continued from page 19)

across the bow at the steady state theorists. If it existed, the CMB would clearly indicate that the universe had once been different—smaller and hotter—from the way it is today. Thus the first direct observations of the CMB were nails in the coffin for the steady state theory. Those observations were made inadvertently in 1964, by Arno Penzias and Robert Wilson of Bell Telephone Laboratories—Bell Labs, for short—in Holmdel, New Jersey. Little more than a decade later, Penzias and Wilson won a Nobel Prize for their persistent work (and good luck).

By the early 1960s physicists all knew about microwaves, but almost no one had the technology to detect weak signals in that part of the spectrum. Back then most wireless communication was done with radio waves, which have longer wavelengths than microwaves, and so the existing receivers, detectors, and transmitters weren't suitable for the task. You needed a shorter-wavelength detector for microwaves and a sensitive antenna to capture them. And Bell Labs had one: a king-size, horn-shaped antenna that could focus and detect weak signals.

If you're going to send or receive a signal, you don't want other things contaminating it. Penzias and Wilson were looking at radio emissions from the Milky Way galaxy, and they wanted to pin down the sources of background interference—from the Sun, from the center of the galaxy, from terrestrial sources, from whatever. So they made an innocent measurement. They weren't cosmologists; they were radio astronomers, unaware of the predictions by Gamow, Alpher, and Herman. What they were decidedly *not* looking for was the cosmic microwave background.

So Penzias and Wilson made their observations, and corrected their data for the sources of interference they knew about. But there was a background noise in the signal that just didn't go away, and they couldn't figure out how to get rid of it. It seemed to come from every direction, and it didn't change. Finally they looked inside the antenna, and what greeted them was a flock of nesting pigeons, surrounded by liberal deposits of a white dielectric substance: pigeon poop. Could the droppings, they wondered, be responsible for the background noise? The only thing that was all over their fancy horn-shaped antenna yet didn't change was the pigeon poop. So they cleaned it out, and sure enough, the noise dropped a bit. But it still wouldn't go away. The paper they published in 1965 in *The Astrophysical Journal* refers to the persistent puzzle as inexplicable "excess antenna temperature."

While Penzias and Wilson were scrubbing bird droppings off their antenna, a team of physicists at Princeton University, led by Robert H. Dicke, were building a detector specifically to find the CMB. The professors, however, didn't have the resources of Bell Labs, so their work went a little slower. The moment Dicke and his colleagues heard about Penzias and Wilson's work, they knew they'd been scooped. The Princeton team knew exactly what the "excess antenna temperature" was. Everything fit: the temperature, the fact that the signal came from every direction, and that it wasn't linked in time with Earth's rotation or position around the Sun.

Inside the antenna were liberal deposits of a white dielectric substance: pigeon poop.

Because light takes time to reach us from distant places in the universe, we are actually looking back in time when we look into space. So if, while we were watching, the intelligent inhabitants of a galaxy far, far away were measuring the temperature of the cosmic background radiation for themselves, they should get a temperature somewhat higher than 2.7 degrees Kelvin, because they are living in a younger, smaller, hotter universe.

Can such a mind-bending assertion be tested? Yup. Turns out that a molecule called the cyanogen radical gets excited by exposure to microwaves. If the microwaves are warmer than the ones in "our" CMB, they will excite cyanogen radicals a little more than our microwaves do. The cyanogen radicals in distant, and thus younger, galaxies ought to be exposed to a warmer cosmic background than the cyanogen radicals in our galaxy, the Milky Way. So their cyanogen radicals ought to live more excited lives than ours. And they do: the spectrum of cyanogen radicals in distant galaxies shows the microwaves to be just the temperature they should have been at the time the radiation left the galaxies on its journey to Earth.

You can't make this stuff up.

But why is the CMB interesting? The universe was opaque until 380,000 years after the big bang, so you couldn't have witnessed matter taking shape even if you'd been sitting front-row center. You couldn't have identified where the galaxy clusters and voids were starting to form. Before anybody could have seen anything worth seeing, photons had to travel, unimpeded, across the universe.

The spot where each photon began its cross-cosmos journey is where it smacked into the last electron that would ever stand in its way. As more and more photons escaped without being deflected by electrons, they created an expanding shell that astrophysicists call the "surface of last scattering." That shell, which formed over a period of some 120,000 years, is where and when the first atoms in the cosmos were born.

By then, matter in large regions of the universe had already begun to coalesce. Where matter accumulates, the

strength of gravity grows, enabling more and more matter to gather—a snowball effect. Those matter-rich regions seeded the formation of planets, stars, and galaxies, while other regions were left relatively empty. The photons that last scattered off electrons in the coalescing regions developed a different, slightly cooler profile as they climbed out of the strengthening gravity field.

When we astrophysicists map the CMB in detail [*see "Sharper Focus," by Charles Liu, May 2003*], we find that it's not completely smooth. It has spots that are slightly hotter or slightly cooler than average, by one hundred-thousandth of a degree. We know what matter looks like today because we see galaxies, galaxy clusters, and galaxy superclusters. To figure out how those systems arose, we probe the cosmic microwave background, a remarkable relic of the remote past. Studying its patterns is like doing cosmic phrenology: feeling the bumps on the "skull" of a youthful universe to infer its behavior not only as an infant but also as a senior citizen.

The most detailed map of the CMB ever made is the survey unveiled this past February by the Wilkinson Microwave Anisotropy Probe (WMAP). WMAP data enable astrophysicists to compare, for instance, the distribution of sizes and temperatures of the warm and cool areas. From that comparison the strength of gravity in the early universe can be inferred, and thus how quickly matter accumulated. From that the relative amounts of ordinary matter, dark matter, and dark energy in the universe can be calculated (the percentages are 4, 23, and 73, respectively), and from those percentages it's easy to tell whether or not the universe will expand forever.

Ordinary matter is what everyone is made of. It exerts gravity and can absorb, emit, and otherwise interact with light. Dark matter, however, is a mysterious substance that exerts gravity but does not interact with light in any known way. Dark energy is a mysterious pressure that counteracts gravity, forcing the universe to expand faster than it otherwise would. The phrenology exam confirms that cosmologists understand how the early universe behaved, but it also demonstrates that most of the universe, then and now, is made of stuff they're clueless about.

Profound areas of ignorance notwithstanding, today, as never before, cosmology has an anchor. The CMB is the vestige of a portal through which everything we are made of once passed: the surface of last scattering. From the fascinating physical processes whose traces are imprinted on that surface, a great deal can be learned about the universe both before and after its light was set free.

The simple discovery of the cosmic microwave background turned cosmology into something more than mythology. But it was the detailed mapping of the CMB that secured cosmology's place at the table of experimental science.

Cosmologists have plenty of ego: how else could they have the audacity to deduce what brought the universe into being? But the new era of modern, observational cosmology ushered in by the WMAP data may call for a more modest, less freewheeling stance among its practitioners. For each new observation, each morsel of data, wields a double-edged sword: it continues to build the kind of foundation for cosmology that so many other sciences enjoy. But it will also dispatch some of the tall tales theorists dreamed up before there were enough data to declare them fantasies.

Yes, cosmology has come of age.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City. Videotapes of a dozen of his lectures, under the title "My Favorite Universe," were recently released by the Teaching Company (www.teachco.com). *All twelve are based on essays that have appeared in* Natural History.

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Petra: Lost City of Stone

October 18, 2003–July 6, 2004

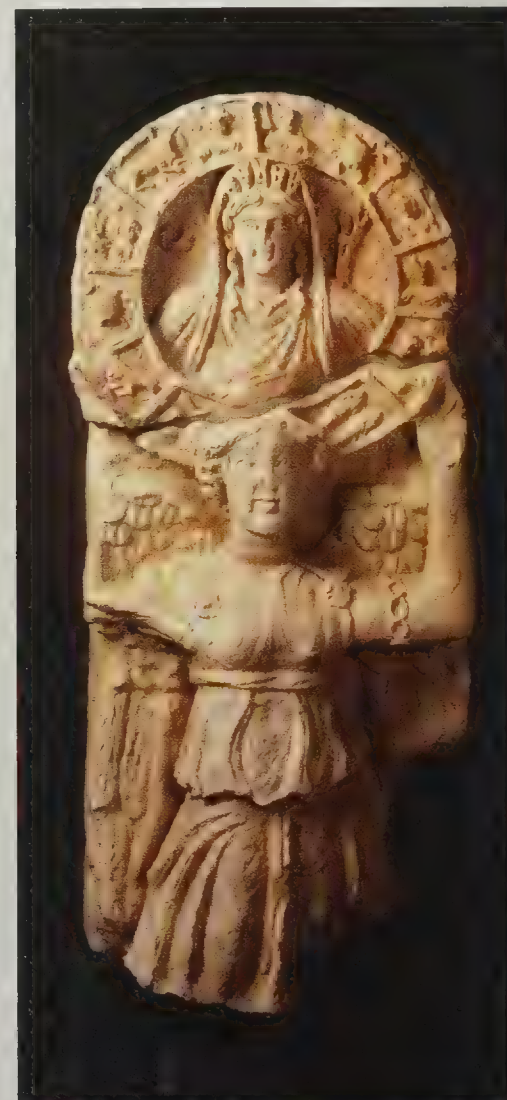
Literally carved from the red sandstone cliffs in the Jordan Rift Valley is the ancient city of Petra, now mostly in ruins. *Petra: Lost City of Stone,* opening at the American Museum of Natural History on October 18, 2003, tells the story of this thriving metropolis at the crossroads of the ancient world's major trade routes and of the technological virtuosity that allowed its founders, the Nabataeans, to build and maintain a city in the harsh desert environment. Developed in collaboration with the Cincinnati Art Museum and presented under the patronage of Her Majesty Queen Rania of Jordan, *Petra* is the first major cultural collaboration between Jordan and the United States and the most complete portrait ever mounted on the amazing yet enigmatic city of Petra and its people.

"With its complex intermingling of nature and culture," said Museum President Ellen V. Futter, "the fascinating story of Petra mirrors the very work and mission of the Museum. For more than 130 years, our curators have studied relationships between nature and humanity. Understanding how the underpinnings of other cultures flourish, and how they grow and spread has perhaps never been more relevant than it is today, as we embrace the challenges and opportunities of living in a truly global community."

Petra: Lost City of Stone features approximately 200 exceptional objects on loan from collections in Jordan and Europe, many on view for the first time in the United States, and from collections in the United States. Stone sculptures and reliefs, ceramics, metalwork, stuccowork, ancient inscriptions, and a selection of some 25 19th-century paintings, drawings, and prints will be displayed alongside architectural sections from several of Petra's famous monuments.

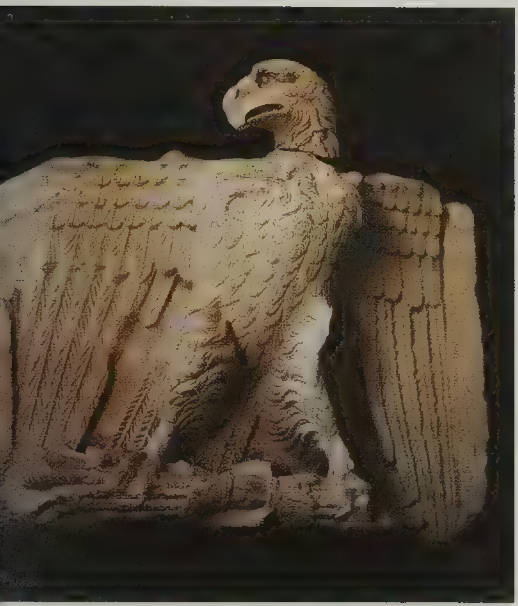
This rare and delicate glass mosaic fragment of a man's head formed a part of the extraordinary wall mosaics that decorated Petra's Byzantine basilica.

First conceived by the Cincinnati Art Museum in 1994, *Petra: Lost City of Stone* has been organized by the American Museum of Natural History and the Cincinnati Art Museum. The American Museum of Natural History has been renowned for more than 130 years as a leader in archaeological fieldwork and research, and has a long tradition of presenting exhibitions that illuminate complex cultural and scientific issues. The Cincinnati Art Museum (CAM), one of the oldest and most important visual arts institutions in the United States, has an extraordinarily rich permanent collection representing many cultures and historical periods, including the most extensive and important collection of Nabataean artworks outside Jordan. CAM's Nabataean collection was excavated in 1937 at the site of Khirbet Tannur and was originally divided between American and Jordanian authorities. This exhibition will reunite the two collections, which contain some



For the first time since antiquity, the two original halves of this important Nabataean statue will be united for the exhibition *Petra*. This image, taken several years ago, shows the authentic upper half of the statue (in the collection of the Cincinnati Art Museum) together with a cast of the lower portion of the original, which resides in Amman, Jordan.

of the most important works of Nabataean art extant. The Jordanian Ministry of Tourism and the Department of Antiquities, as well as the American Center for Oriental Research in Amman, have assisted with the development of this project. After its premiere at the American Museum of Natural History, *Petra* will travel to other venues throughout the United States including CAM.



This eagle, a Nabataean symbol of celestial power, sits atop a thunderbolt, an ancient symbol of the heavens and of the storms they produce.

Among the highlights of *Petra: Lost City of Stone* will be several important architectural pieces, such as a sculpted garland frieze from a major temple at Petra, a sculpted window frame from a private villa, a portion of a monumental temple façade featuring figures from the zodiac, and a limestone pulpit from a sixth-century Byzantine church. Key masterworks will include a monumental limestone head of a Nabataean male deity, a seated sandstone cult statue of a storm god, a life-size cast bronze statue of the goddess Artemis, and a marble head of a Roman emperor.

One notable display will unite two halves of a sculpture believed to have been broken during an earthquake and separated some 1,500 years ago. The top of the sculpture, which depicts the 12 signs of the zodiac surrounding a bust of Tyche, a Nabataean goddess, resides in CAM's collection, while the bottom is held at the National Archaeological Museum in Amman, Jordan. In *Petra,* the two halves of this intriguing piece will be reunited as a complete statue for the first time in 1,500 years.

From the second century B.C., through the second century A.D., Petra prospered—it is estimated that at its height, the city was as large as lower Manhattan, with a population of more than 30,000. As the city grew to link far-flung regions of the ancient world, a cultural merging occurred that is expressed through the unique style of art and architecture found at the site, representing the heterogeneous nature of its society. A massive earthquake in A.D. 363, however, destroyed much of Petra. Although partially revived after that, Petra was no longer the economic powerhouse it had been. Much of the technological infrastructure that had made life in Petra possible fell into disuse, and political and religious changes in the ancient world led to the eventual abandonment of the city in the seventh century A.D.

The city was then "lost" to Westerners until a series of European explorers rediscovered it. In 1812, Swiss explorer Johann Ludwig Burckhardt reawakened European knowledge of the site's existence after more than 1,000 years. The theme of European rediscovery of the ancient site also will be explored through paintings, drawings, and prints by David Roberts, William Bartlett, Edward Lear, and Frederic Church, including Church's large-scale oil painting of the famous Treasury (1874).

Petra remains a source of deep fascination for Western visitors, with its savage beauty and natural grandeur, its desolate setting, the mystery and splendor of its rock-carved architectural ruins, and the variegated color of its cliff faces.

"Petra is one of the world's most spectacular archaeological sites, combining an extraordinary natural landscape and monumental buildings," said Craig Morris, Senior Vice President, Dean of Science, and Curator, Division of Anthropology at the Museum. "The exhibition re-creates many aspects of this impressive natural and human setting using artworks, photographs, and actual architectural elements to tell the fascinating story of life in this ancient city using the eloquent beauty of the work of its people."

In New York, Petra: Lost City of Stone *is made possible by Banc of America Securities and Con Edison.*

The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal.

This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.

COMPANION EXHIBITION

The Bedouin of Petra

October 18, 2003–July 6, 2004

Photojournalist Vivian Ronay's evocative color photographs taken between 1986 and 2003 document the Bdoul group of five sedentary Bedouin tribes living around the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

PANEL DISCUSSION

The Petra Siq

Sunday, 10/19, 2:00 p.m.

Petra's remarkable hydraulic system, designed over 2,000 years ago, transformed a semi-arid land into a lush environment. The same conditions that challenged the Nabataeans complicate conservation efforts at the Petra site today. In this panel discussion, Aysar Akrawi and Ma'an Huneidi of the Petra National Trust, and Douglas C. Comer of Cultural Site Research and Management, will illustrate how archaeology and satellite imagery have influenced conservation measures at Petra.

MUSEUM EVENTS

EXHIBITIONS

The Butterfly Conservatory
Opens October 11
The butterflies are back! Mingle with more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat.

The Butterfly Conservatory is made possible through the generous support of Bernard and Anne Spitzer.

Vietnam: Journeys of Body, Mind & Spirit
Through January 4, 2004
This comprehensive exhibition presents Vietnamese culture in the early 21st century.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

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Through January 4, 2004

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LECTURES

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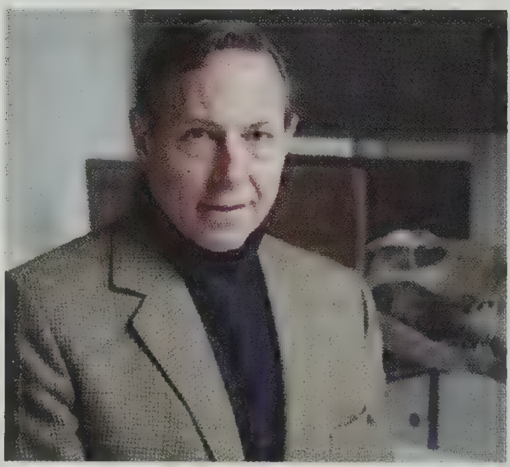
Thursday, 10/9, 7:00 p.m.
Melanie Stiassny and Mark Siddall describe the spectacular renovation of the Milstein Family Hall of Ocean Life.

Sea Dragons: Predators of Prehistoric Seas
Wednesday, 10/22, 7:00 p.m.
Richard Ellis discusses the lives, deaths, reproductive habits, and hunting strategies of the giant marine reptiles of the Mesozoic era.



RICK EDWARDS

Richard Ellis

Curator's Lecture: Arthur Ross Hall of Meteorites
Thursday, 10/23, 7:00 p.m.
Denton S. Ebel will discuss 21st-century perspectives on the oldest rocks in the solar system.

The Extraordinary Sea Voyages of Captain James Cook
Tuesday, 10/28, 7:00 p.m.
Anthropologist Nicholas Thomas brings Captain James Cook to life.

WORKSHOP

Animal Drawing
8 Thursdays, 10/2–11/20, 7:00–9:00 p.m.
An intensive after-hours drawing course among the Museum's famed dioramas and dinosaurs.

FAMILY AND CHILDREN'S PROGRAMS

It's a Wild, Wild World
Live animal presentations and hands-on workshops.
Saturday, 10/11: *Raptors: Birds of Prey*
Saturday, 10/18: *The World of Reptiles*

Watch Out! Meteorites on the Big Screen
Sunday, 10/26, 2:00–3:30 p.m.
Clips from classic science fiction films illustrate the myths and realities of meteorite impacts.

HAYDEN PLANETARIUM Programs

Virtual Universe: Orion Nebula
Tuesday, 10/7, 6:30–7:30 p.m.
Redefine your sense of "home" on this monthly tour through charted space.

Celestial Highlights: Another Eclipse!
Tuesday, 10/28, 6:30–7:30 p.m.
Find out what's up in the November sky.

Celebration of Space: Far Out: Space Probes as Landscape Photographers
Monday, 10/20, 7:30 p.m.
A panel of scientists, photographers, philosophers, and poets will discuss the role of planetary images on the art and politics of the human condition.

A Weather Report from an Extrasolar Planet
Monday, 10/27, 7:30 p.m.
With Dimitar Sasselov, Harvard-Smithsonian Center for Astrophysics.

Courses

Stars, Constellations, and Legends
5 Wednesdays, 10/15–11/19,
6:30–8:00 p.m.
Learn to locate and identify the seasonal constellations.

Using a Telescope
4 Mondays, 10/20–11/10,
6:30–8:30 p.m.
Ideal for those who have a telescope but are not sure how to use it, this course covers the basic functioning of telescopes.

Introduction to Astronomy
6 Mondays, 10/20–11/24,
6:30–8:30 p.m.
Designed for those with no background in astronomy, mathematics, or physics.

Stars: Binaries and Clusters
6 Thursdays, 10/23–12/11,
6:30–8:30 p.m.
Explore single stars, binary stars, star clusters, and galaxies to find out what the study of these objects can tell us about the universe.

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Foundations of Science: Archaeo/Ethno-Astronomy
6 Thursdays, 10/16–11/20,
6:30–8:30 p.m.
Cosmologies from diverse societies and the symbolism associated with them.

The Rose Center: Envisioning the Virtual Universe
5 Tuesdays, 10/14–11/18,
6:30–8:30 p.m.
Tours and hands-on control of the Hayden Planetarium's computer-generated cosmos.

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The Salt *Not* of the Earth

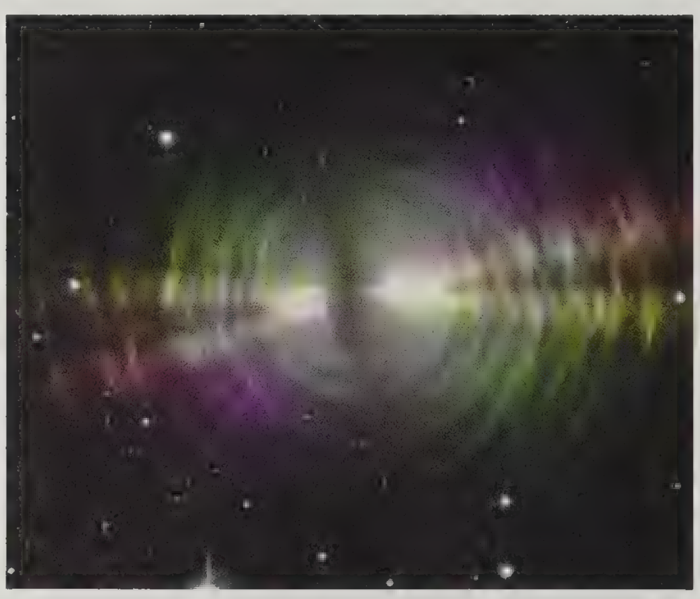
Throughout the Egg Nebula, astrochemists have detected—what else?—sodium chloride.

By Charles Liu

Chemistry, to most of us, means test tubes, Bunsen burners, and beakers filled with bubbly concoctions. A select group of chemists, however, rarely handle flasks of foul-smelling fluids. Instead, telescopes are their glassware, and the stars, their crucibles. They study astrochemistry—the creation and transformation of molecules and compounds in the universe.

The astrochemical laboratory is the hyperrarefied, mostly weightless, extreme-temperature environment people colloquially call outer space. In space, atoms can combine to form molecules one can't ordinarily find on Earth. Conversely, many compounds common on our planet practically never occur outside a rock-iron planet with a thick, gaseous atmosphere.

Take ordinary table salt. A union of a single sodium atom with a single chlorine atom, salt (or, as chemists call the compound, sodium chloride) is ubiquitous on Earth: it permeates our oceans, our food, and our blood, not to mention the massive veins of the stuff in the Earth. Beyond our solar system, though, it had, until recently, been detected in only one place: in the vicinity of a dying, carbon-heavy star known as IRC +10216, in the constellation Leo. Now, though, a team led by Jaime L. Highberger, an astrochemist at the University of Arizona in Tucson, has reported the discovery of a sprinkling of salt in a cloud of gas and dust named CRL 2688, in the constellation Cygnus, the swan. Because of its roughly oval shape and its position at the tail end of a constellation named for a bird, the cloud has long been known as the Egg Nebula.



Clouds of dust and gas that make up the Egg Nebula, visible here as roughly circular arcs, are sloughed off in a series of outward puffs from an aging, central star (positioned, but not visible, at the center of this image) that is transforming itself from a red giant into a white dwarf. The colors of the image are not true colors, but instead represent various angles of polarization that are imposed on the starlight as it passes through the dust. Astrochemists surveying the clouds' dust and complex molecules have found ordinary table salt, NaCl, among the gaseous compounds there.

Molecules are far more complicated than the sum of their parts. The bonds between the individual atoms aren't as rigid as the sticks and balls of chemistry models suggest. Underinflated beach balls held together by bedsprings make a better analogy; molecules are wobbly constructions, constantly flopping, spinning, and flexing. As a consequence, they can absorb and emit radiation, just as single atoms can—and it is their radiation-emitting property that enables astronomers to find them.

Their structural complexity, however—all that flopping, spinning, and flexing—ends up complicating their spectroscopic signatures, making them far harder to interpret than the spectra of solitary elements. On top of that, when molecules "glow" in open space, their glow is a cold one, generally in the microwave region of the electromagnetic spectrum, where wavelengths are thousands of times longer than they are for visible light. To see them, astrochemists must focus on them with specialized radio telescopes.

Figuring out how (and where) various kinds of molecules might form in space is even trickier than detecting their presence. Free-floating atoms in interstellar gas clouds can't just collide and stick together. In most cases, such concentrations of atoms are so rarefied that the chances of colliding are infinitesimal. Even if atoms do collide, they have too much kinetic energy to stick. The atoms just bounce off each other and keep going.

Instead, molecules have to form on the surfaces of dust grains. There the collisions are likely enough, and the environment is quiet enough, for chemical reactions to take place. Atoms need to land on a grain, meet, and create a molecular bond. Then, the newly formed molecule needs to float off the grain back into space.

It turns out that almost all the free-floating molecules in

space are extremely simple ones: either hydrogen gas or carbon monoxide. For heavier and more complex molecules, though, aging stars, replete with larger atoms, are an ideal place to look. Stars of about the same mass as our Sun (but older) go through a red-giant phase before becoming white dwarfs. The outer layers of a red giant slough off in a series of outward puffs of gas, forming a planetary nebula—a system of rings and loops of glowing gas around the star. The planetary nebula around such a star is rich in dust grains as well as heavy elements, and its internal heat can provide enough energy to build compounds. But the nebula is not so hot that it breaks the delicate molecular bonds.

That's why Highberger and her colleagues looked at CRL 2688, a star in the last stages of red gianthood—and the planetary nebula forming around it. Observing with the twelve-meter radio telescope at Kitt Peak in Arizona, and with the thirty-meter IRAM radio telescope at Pico Veleta, Spain, they found unmistakable evidence that the Egg Nebula is salty.

Finding molecules in space has its own rewards, but the work is more than just a search for curiosities. The distribution of salt in the Egg Nebula gives important information about how stars recycle their contents, providing raw materials to make new stars. Highberger's observations show that the free-floating salt occurs in roughly spherical layers more than a trillion miles from the central star. At such distances the salt should be so cold it should all have condensed into solid grains, which are undetectable to astrochemists. Since the salt is clearly observed, a puzzle arises: How has all this vaporized salt survived?

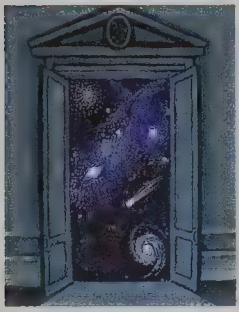
One possibility is that astronomers simply don't understand gaseous salt well enough yet. Perhaps temperatures have to be much colder before solid salt can form.

Highberger and her colleagues suggest another scenario. As the central star sheds its outer layers, they drift outward at varying times and speeds. If a fast-moving layer puffs outward shortly after a slower-moving layer, the newer material would ultimately crash into the older stuff. The resulting shock wave would stir up cold gas and reheat it. The heat would trigger a new wave of molecule formation, and produce the glowing gaseous salt that is observed. If the model is correct, I'd say the Egg Nebula isn't just salted; it's scrambled and fried, too.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN OCTOBER

By Joe Rao



Always hasty, Mercury makes a brief appearance before dawn early this month, rising just above the due-eastern horizon. It soon disappears into the glare of the Sun and reaches superior conjunction (on the other side of the Sun as seen from the Earth) on October 25th.

Venus, shining brilliantly at magnitude –3.9, chases the Sun across the sky throughout October. As seen from midnorthern latitudes, the planet sets thirty minutes after the Sun on the 1st; by the 31st, because of both shortening days and Venus' own movements, the planet sets about an hour after our star. On the evening of the 26th it appears just to the right of a very young crescent Moon.

Mars, shining in the constellation Aquarius, crosses its highest point in the sky about three to four hours after sunset. How it has dimmed in the past few weeks! As its distance from Earth increases from 42 to 58 million miles during October, Mars fades to less than half its early-month splendor, from magnitude –2.1 to –1.2.

The king of the heavens meets the king of the jungle: Jupiter is in the constellation Leo. It rises about two-and-a-half hours before the Sun at the beginning of the month and more than four-and-a-half hours before sunrise on Halloween. On the morning of the 22nd Jupiter is well to the right of the waning crescent Moon.

Saturn, in the constellation Gemini, rises out of the northeast about five hours after sunset at the beginning of the month; by the time the hobgoblins and ghouls are out and about on the 31st it is rising less than four hours after sunset. Saturn's rings continue to be a spectacular sight, even through a small telescope. On the night of the 16th Saturn appears to hover above the Moon in the east-northeastern sky; by the 17th the Moon shifts far east of the planet.

The Moon reaches first quarter on the 2nd at 3:09 P.M. and waxes full on the 10th at 3:27 A.M. Traditionally the full Moon following the Harvest Moon is known as the Hunter's Moon. The Moon wanes to last quarter on the 18th at 8:31 A.M., and the new Moon arrives on the 25th at 8:50 A.M.

"Fall back" in much of Canada and the United States, as daylight saving time ends on Sunday, the 26th; the hour between 1 A.M. and 2 A.M. is officially repeated.

Unless otherwise noted, all times are given in Eastern Daylight Time.

Pees & Cues

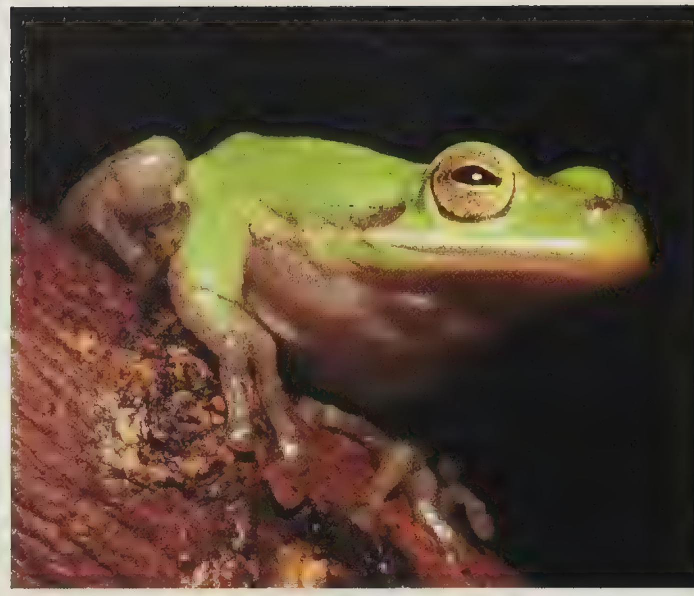
By Ryan C. Taylor

My academic life at the University of Louisiana in Lafayette came to a crossroads the day Bryant "Buck" Buchanan placed a squirrel treefrog *(Hyla squirella)* in my hand. In the blink of an eye, the small green frog slipped from my grip and rocketed across the lab, leaving a puddle in my palm. Somehow, in midflight, it latched onto some metal shelving with one foot and hung on for dear life. In my astonishment all I could do was wipe off what was left on my hand.

Until that moment I had been a gung ho fish guy, planning a research career in marine biology. But for some reason I found the treefrog experience so amusing that when Buck offered me the chance to study the creatures with him, I accepted on the spot. Our aim was to find out why treefrogs so frequently do just what my little guy had done to me: dump their bladder water when they feel threatened.

A few days later Buck brought me into the field to get me better acquainted with our research subjects. Wading through fronds of chest-high dwarf palmettos in the dense understory of a hardwood forest in St. Landry parish, we talked about the frogs and our approach to the project. I had already seen that they are no bigger than most car-alarm remotes: about an inch and a quarter, on average, from snout to cloaca. Daytime conditions in their native habitat in the southeastern United States are warm and often baking. Hence, by day, squirrel treefrogs nestle into dense vegetation, pressing themselves flat against a leaf and tucking their feet under the body, to expose as little skin as possible to the drying effects of the air. But, I learned, such a water-conserving posture is not always enough to prevent dehydration. That's why the frogs take the added precaution of storing water in their bladders, in the form of dilute urine. The bladder water is essential to their survival.

Yet even in the dry season, from September to November, treefrogs often dump their precious bladder water when potential predators approach—that much was evident from my first treefrog experience. Could dumping its bladder benefit a frog by lightening its load, thereby increasing the distance it could jump? Buck and I decided to find out.



An amphibian charmer, Hyla squirella

Our first step was to measure how much bladder water squirrel treefrogs retain. By weighing adult males with full and then empty bladders, we found that bladder water makes up, on average, 14 percent of the animal's entire body weight. To our amazement, one treefrog was storing 59 percent of its total body weight as bladder water—the equivalent of a 175-pound man whose bladder is holding more than twelve gallons of water.

Our next step was to test the frogs' jumping. We weighed each frog as soon as it rehydrated, and then let the animals loose one by one inside a plastic-lined "arena." Some of the frogs—apparently those that were more skittish—dumped their bladders; others didn't. But they all jumped, either spontaneously or after a gentle prod. We then measured their jumps and weighed them again. Our data showed that the frogs with empty bladders jumped nearly 20 percent farther than the frogs with full ones.

By the end of our study I realized that, when danger threatens, treefrogs face a potentially life-altering decision: To pee, or not to pee. By jettisoning their bladder water, they gain an advantage in getting out of harm's way, but at the likely cost of dehydration. I also realized that, like the frogs, I, too, faced a life-altering choice. I could continue down the road to marine biology, or stick with my newfound amphibian friends. Let's just say I never really recovered from the treefrog experience.

Ryan Taylor is finishing his doctoral research at the University of Louisiana in Lafayette on the factors that influence mate choice in squirrel treefrogs.

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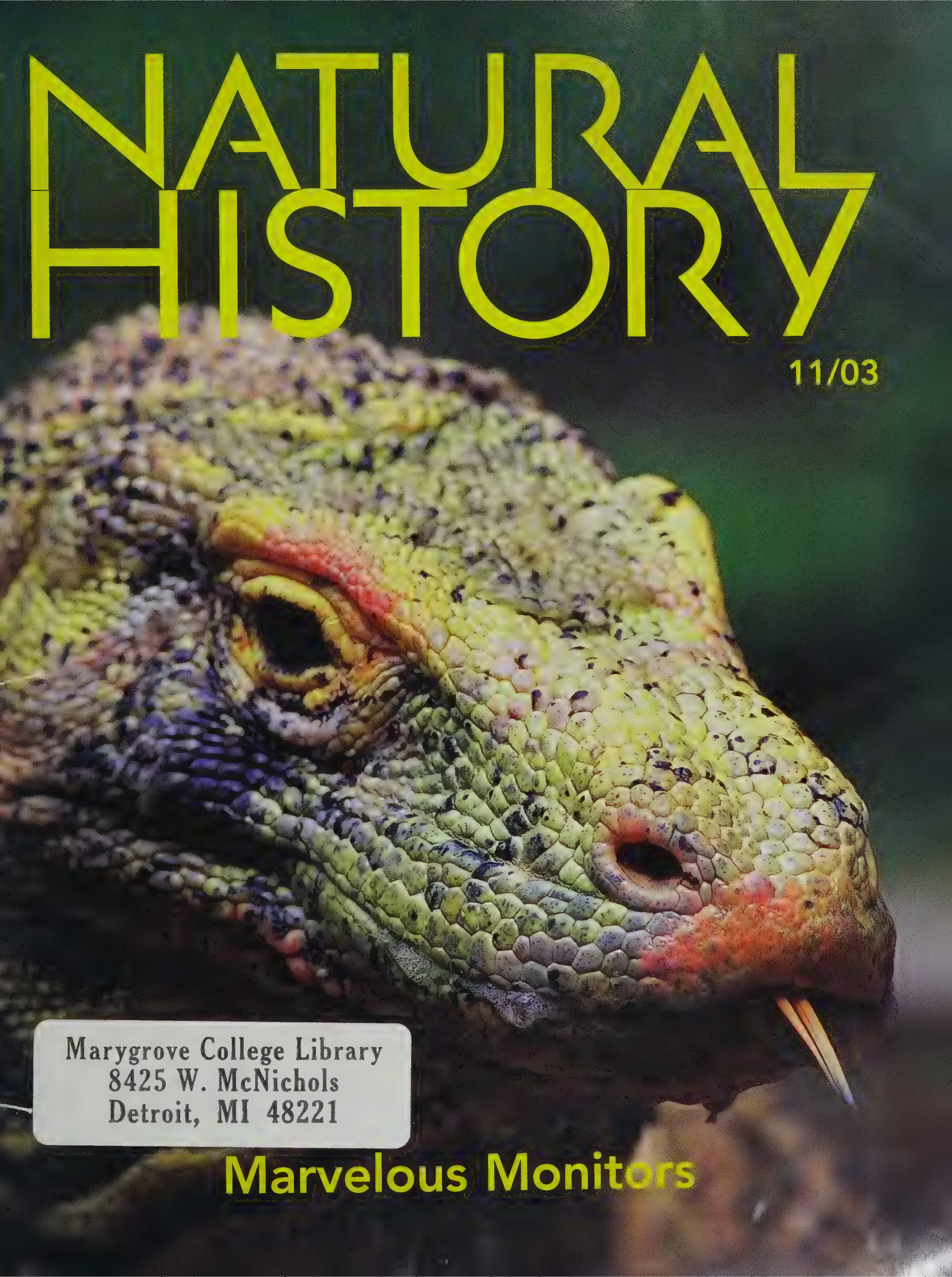
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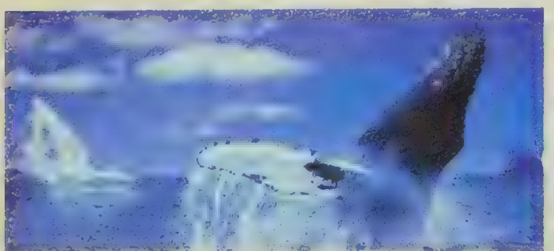

Antarctica

Penguin fossil expert Julia Clarke leads this extraordinary expedition to the Antarctic Peninsula aboard the new ship *Orion*. Via ship and Zodiac boats, you'll visit busy penguin rookeries, encounter whales and seals, and witness an ever-changing panorama of tabular icebergs and snowcapped mountains.

January 29 - February 11, 2004
Study Leader: Julia Clarke,
American Museum of Natural History

Antarctica, South Georgia, and the Falklands

Explore the natural and geological wonders of Antarctica with geologist Malcolm McKenna and Trevor Potts, an expert on Polar explorer Ernest Shackleton. In addition to Antarctica you'll visit Elephant Island, where Shackleton's crew took refuge; the remote Falkland Islands; and spectacular South Georgia.

February 18 - March 11, 2004
Study Leader: Malcolm McKenna,
American Museum of Natural History emeritus

The Mighty Amazon

Join ornithologists Francois Vuilleumier and Paul Sweet on an extraordinary 2,000-mile journey along this storied river. Via ship and Zodiac boats, you'll venture into a labyrinth of narrow tributaries, trek through the rain forest, and visit isolated river villages, everywhere encountering the region's remarkable wildlife.

March 30 - April 17, 2004
April 15 - May 2, 2004
Study Leaders: Francois Vuilleumier & Paul Sweet, American Museum of Natural History

Sicily: Crossroads of Mediterranean Civilizations

With its treasures from throughout the ages, Sicily is a virtual living museum. On this unique circumnavigation you'll see some of the most important remains from the Greek, Roman, Byzantine, and Renaissance periods.

June 1 - 11, 2004
Study Leader: TBA

The Circumnavigation of Newfoundland

Naturalists Alan and M.J. Brush team up with whale expert Pierre Beland on this in-depth exploration of Newfoundland. Excursions include Witless Bay Ecological Reserve; Terra Nova National Park; Twillingate Island; Gros Morne National Park; and the ancient Viking settlement at L'Anse Aux Meadows.

June 11 - 19, 2004
Study Leaders: Alan and M.J. Brush, American Museum of Natural History, and Pierre Beland, St. Lawrence National Institute of Ecotoxicology

Treasures of the Adriatic Sea

Discover the extraordinary art and architecture that can be found in the string of unspoiled cities lining the Adriatic. The itinerary includes Venice, Split, Mostar, Dubrovnik, Kotor, Ravenna, and the unusual hilltop Trulli villages.

June 26 - July 6, 2004
Study Leader: Anne-Marie Bouché,
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The Great Lakes

Discover all five of the Great Lakes on this fascinating journey through the American heartland. Highlights include the scenic Thousand Islands of Lake Ontario, Whitefish Point Bird Observatory, beautiful Mackinac Island, Niagara Falls, and a traditional Native American powwow.

July 17 - 25, 2004
Study Leader: Al Duba,
American Museum of Natural History

Greenland and the Canadian Arctic

Experience the abundant wildlife and the captivating landscapes of the Far North on this study voyage along the rugged coasts of Greenland and northern Canada. You'll also witness the fascinating art and culture of the native Inuit people.

July 24 - August 6, 2004
Study Leader: Francois Vuilleumier,
American Museum of Natural History
August 20 - September 2, 2004
Study Leader: Robert Rockwell,
American Museum of Natural History

Journey of Odysseus

Journey into the realm of gods, nymphs, and monsters on this voyage that traces the epic travels of Odysseus. Excursions include Troy, where Odysseus' journey began; Mycenae, the kingdom of Agamemnon; Malta, home of Calypso; Sicily; and Ithaca, the hero's long-sought home.

October 7 - 21, 2004
Study Leader: Daniel Mendelsohn,
Princeton University

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FEATURES

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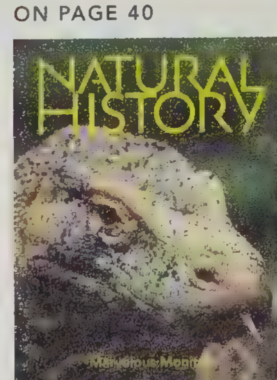
COVER
Komodo monitor

STORY BEGINS ON PAGE 40



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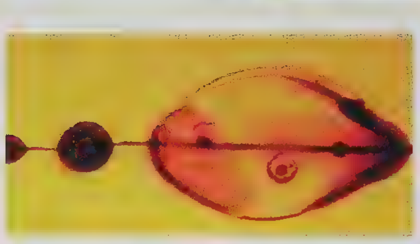
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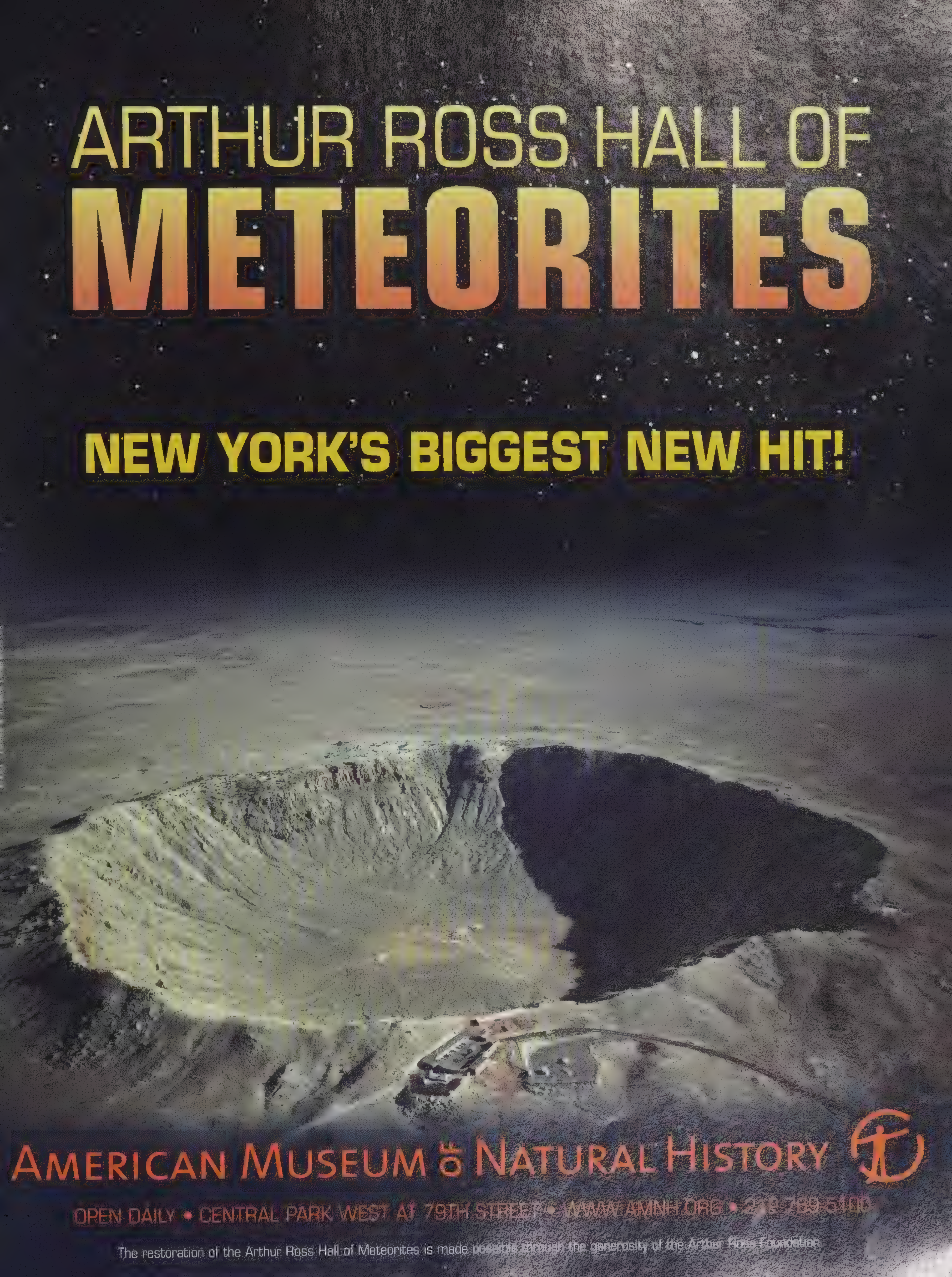
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A Well-Dressed Bird

Photograph by Anup Shah

NATURAL MOMENT

preceding pages

Cutting the cake, carving the Thanksgiving turkey, or getting first crack at tearing into wildebeest flesh, as the case may be, is an honor usually bestowed upon the senior or perhaps showiest member of the dining party. On the savannas of eastern Africa, the Nubian or lappet-faced vulture *(Torgos tracheliotus)* is king of carrion. With thick, industrial-strength beaks, Nubians are often the only birds that can puncture tough hides—which makes weaker scavengers depend on them for access to the meat of a carcass. The massive vultures also use their might to fend off hyenas and snap up the occasional live flamingo.

Wildlife photographer Anup Shah was in Kenya's Maasai Mara National Park early one overcast morning, keeping his eye on a kill site, when the lappet-faced vulture pictured here arrived—unfashionably late. Minutes earlier, two lions had brought down a wildebeest, and already a spotted hyena, two black-backed jackals, and about twenty-five white-headed and Ruppell's griffon vultures were busily feasting.

The Nubian, after landing close by, did not attract much attention, so it opened its wings—a full nine feet across—to expose a puffed-up chest and downy underfeathers. "After swaggering around in an exaggerated manner," Shah said, the bird found a place among the others and commenced its meal. In less than an hour the assembled scavengers had picked the wildebeest's bones clean.

—*Erin Espelie*

UP FRONT

Flushed

Just when you thought you'd become so jaded about assaults on the natural environment that you'd heard it all, along comes a story that manages to stir shock, depression, and outrage anew. Thousands of miles out to sea, in a remote region of the North Pacific Ocean where even sailors seldom venture, is a vast floating mass of plastic junk, stretching across an area the size of Texas. Plastic bleach bottles, tops of spray cans, discarded TV picture tubes, polypropylene lines from fishing nets, plastic cigarette lighters, even toy "rubber duckies" have collected in a huge mass of slowly rotating seawater known as the North Pacific subtropical gyre, which—if you'll forgive the metaphor—has come to resemble a giant toilet bowl of swirling waste.

Is this the secret dumping ground of some evil junkyard Mafia? In fact, according to Charles Moore (see "Trashed," page 46), the effect is a natural one. Rivers of plastic objects are carried by great ocean currents from North America, Japan, and other lands along the North Pacific rim into the gyre. There, much of the detritus, most prominently the plastic, becomes trapped until it can decay—a process that, by some estimates, could take 500 years.

Worse, this environmental disaster is not merely an eyesore and a health hazard for seabirds. Japanese investigators have discovered that plastics can concentrate hydrophobic chemicals a millionfold. Those chemicals include such toxic substances as DDT, PCBs, and other oily poisons that have already been dispersed in the oceans. No one knows how such concentrations might affect plankton, fish, or other parts of the food web, but it seems unlikely that any good will come of it.

• • •

Not everyone will find the face of the komodo monitor pictured on this month's cover as endearing as I do, but the creature is certainly a poster child for a group of predatory lizards so wily and intelligent that the epithet "mammal-like" has become a cliché among herpetologists. Ecosystems don't even harbor small monitors and small placental carnivores at the same time. According to Samuel S. Sweet and Eric R. Pianka ("The Lizard Kings," page 40), the reason may be that the two groups play such similar roles.

What I find particularly fascinating about small monitors is their success as cold-blooded (more aptly called ectothermic) animals. They can move about all day, and they can strike like lightning when the circumstances call for it—yet they generally spend far less energy simply living than do their mammalian counterparts. The monitor story spotlights a basic lesson of biology: there are many ways to thrive in a threatening world.

—PETER BROWN

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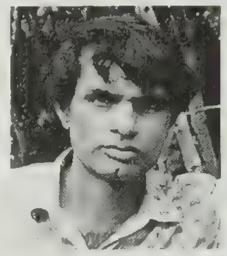
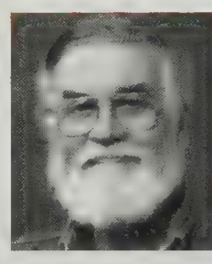
NATURAL HISTORY

A self-taught wildlife photographer, **Anup Shah** ("The Natural Moment," page 6) was born in Kenya of Indian parentage. He credits childhood visits to Nairobi National Park with helping him develop a powerful attachment to African fauna. Shah and his brother Manoj have since teamed up and have been awarded top prizes for their photographic work. Their latest collaborative book, *The Circle of Life: Wildlife on the African Savannah,* will be published next month by Harry N. Abrams.



Samuel S. Sweet ("The Lizard Kings," page 40), an associate professor at the University of California, Santa Barbara, has worked on the ecology of salamanders, snakes, and toads, as well as on the ecology and management of such endangered species as arroyo toads and California tiger salamanders. His studies of monitor lizards have led to two and half years of fieldwork in Australia since 1988. **Eric R. Pianka** is Denton A. Cooley Centennial Professor of Zoology at the University of Texas at Austin. Pianka first studied the lizards of Australia during fieldwork in 1966. Together with the late Dennis R. King, he is co-editor of the forthcoming *Varanoid Lizards of the World* (Indiana University Press). A memoir, *The Lizard Man Speaks,* was published by the University of Texas Press in 1994.



A third-generation resident of Long Beach, California, **Charles Moore** ("Trashed," page 46) is the captain of *Alguita,* an independent oceanographic research vessel. In 1994 he founded the Algalita Marine Research Foundation (www.algalita.org/), dedicated to research, education, and restoration of the marine environment. Since launching his ship in 1995, Moore, who received his captain's license from the U.S. Coast Guard, has conducted ocean and coastal sampling for plastic fragments and debris across a wide swath of the northern Pacific Ocean.

Swiss-born **Paul Schmid-Hempel** ("Fight of the Bumblebee," page 52) earned his doctorate in zoology and ecology at the University of Zurich, and pursued postdoctoral research at the University of Oxford, studying with the behavioral ecologist J.R. Krebs. In 1988 Schmid-Hempel was awarded the National Latsis Prize for his work in evolutionary ecology. Since 1991 he has been a professor at ETH Zürich, the Swiss Federal Institute of Technology. He enjoys opera and hiking in the northern tundra.

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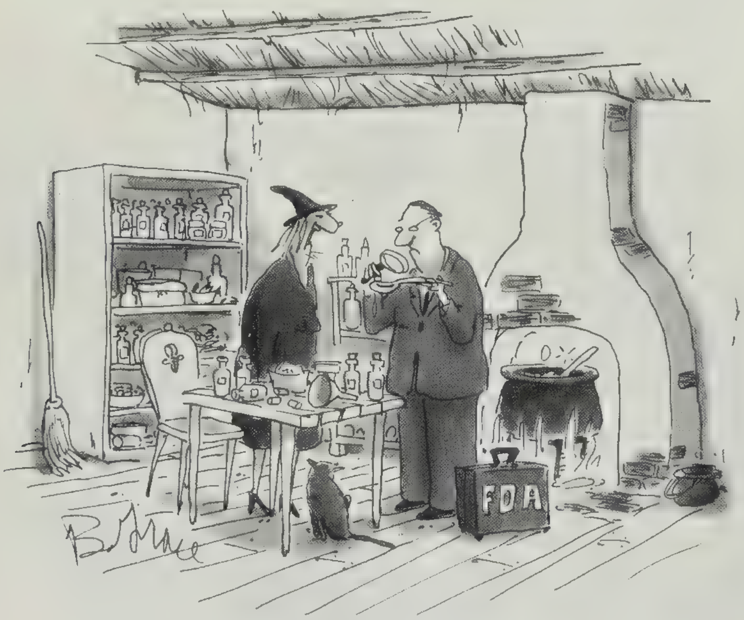
The Light Fantastic

I thought your 9/03 issue was sensational, but one thing puzzled me in Neil deGrasse Tyson's column "In the Beginning," about the early universe. He writes, "By now, one second has passed since the beginning of time. The universe has grown to a few light-years across."

Huh!!?? How could the universe have grown to several light-years across in one second? That would mean it expanded several hundred thousand times faster than the speed of light. Did Einstein's laws not apply at this time?

Hans J. Berliner
Carnegie Mellon University
Pittsburgh, Pennsylvania

NEIL DEGRASSE TYSON REPLIES: During the very early moments of the universe, space-time expanded much, much faster than the speed of light. That staggeringly rapid rate does not violate the principles of Einstein's special theory of relativity, which specifies that an object (or more generally, information) cannot accelerate past the speed of light when traveling within a preexisting space. Einstein's later, more complete general theory of relativity accounts for what can happen to the fabric of space-time itself, and places no restriction on the speed with which that space-time can expand.



"Of course it's full of rodent hairs."

Carl Sagan's Legacy

It was a great comfort to me in 1997, the year following the death of my husband and professional collaborator, Carl Sagan, to read the dedication in Stephen Jay Gould's book *Questioning the Millennium*:

> In loving memory of my friend Carl Sagan
> The most passionate rationalist of our times
> The best advocate for science in our millennium

Steve was learned and highly principled, not one to toss out hyperbolic statements. So I was hurt to discover in Michael Ruse's review of Steve's final book, *The Hedgehog, the Fox, and the Magister's Pox* ["The Mismeasure of Science," 7/03–8/03], the claim that Carl wouldn't "take time out to go to the South and fight the creationists" during the 1981 trial of the Arkansas bill mandating that biology teachers in publicly funded schools evenhandedly discuss both evolution and creationism.

Carl began fighting for science in the dangerous Deep South of 1962, and never stopped as long as he lived. Mr. Ruse's gratuitous swipe at Carl brought to mind another time he was asked to testify against "creationism." It was when he was undergoing one of three bone marrow transplants endured in his heroic struggle for his life. His immune system destroyed by radiation and chemotherapy, emaciated and exhausted, he failed to satisfy the high standards of Mr. Ruse. Instead, he stayed in his hospital room as ordered and wrote *The Demon-Haunted World.*

Ann Druyan
Ithaca, New York

Michael Ruse does Carl Sagan a serious injustice. Sagan had in fact planned to testify at the Little Rock trial, but medical treatment kept him from appearing. He offered to act as a rebuttal witness at the end of the proceedings, but the American Civil Liberties Union's lawyers felt they had already made their case and thus concluded his presence was no longer required.

Frederic Golden
Santa Barbara, California

MICHAEL RUSE REPLIES: As in Akira Kurosawa's film *Rashomon,* the real story is unlikely to emerge at this time. But rather than get into justifications of claims, let me cover my somewhat ungracious reference to Carl Sagan by acknowledging that, in the last half century, he and Steve Gould were two of the most important science popularizers and educators. We owe thanks to both of them.

Whence the Moon

I would like to take issue with three elements in G. Jeffrey Taylor's excellent summary of the legacy of forty years of lunar exploration ["Moonstruck," 9/03].

First, the "giant impact" hypothesis for the origin of the Moon is seriously flawed. There is strong evidence that the lower mantle of the Moon is chemically primitive (chondritic) and could not have been part of either the early Earth or the impactor, nor could it have undergone the heating caused by a giant impact. Serious attention should be given to the hypothesis that the Moon was an independent, co-orbiting planet captured by the Earth.

Second, the Moon was resurfaced by a dozen or so large impacts around 4 billion years ago, not just by the impact that created the huge Imbrium Basin. A cataclysmic period half a billion years long is thus

more likely than one lasting 100 million years.

Third, Mr. Taylor does not note the potential connection between the very early huge lunar impacts that created basins with diameters larger than a thousand kilometers (the oldest being the South Pole–Aitken Basin) and the early evolution of Earth's crust.

Harrison H. ("Jack") Schmitt
Albuquerque, New Mexico

Editor's note: The letter writer is the only geologist to have visited the Moon; in December 1972 he was an astronaut member of the crew of Apollo 17, the last manned lunar mission.

G. JEFFREY TAYLOR REPLIES: I welcome Jack Schmitt's comments. Planetary geologists, however, know little about the lower mantle of the Moon, so no one knows whether it is chondritic. New computer models suggest the giant impact might have taken place when the Earth was half built. Then, as planetary construction was being completed, the Moon could have accreted additional material. Such an explanation combines aspects of both ideas.

The article mentioned that the idea of a relatively brief cataclysm isn't universally accepted. The dissenters' view will be debated until samples have been taken from the South Pole–Aitken Basin and from some of the younger impact basins superimposed on it; that will require a return mission to the far side of the Moon.

Mr. Schmitt's third point is right on: huge early impacts on Earth might indeed have affected how the crust formed and evolved, and even how life originated.

Ask Pooh

Robert M. Sapolsky's article "The Pleasure (and Pain) of 'Maybe'" [9/03] gives fresh meaning to Winnie-the-Pooh's response to Christopher Robin's question "What do you like doing best in the world, Pooh?" We read that Pooh "had to stop and think. Because although Eating Honey *was* a very good thing to do, there was a moment just before you began to eat it which was better than when you were, but he didn't know what it was called."

William J. Rihn
Laguna Beach, California

Night Lights

Until my first week as a Marine grunt in Vietnam, I had never seen fireflies. Reading Sara Lewis and James E. Lloyd's "Summer Flings" [7/03–8/03] brought back strong memories.

It's hard to describe the tension and fear you experience on an all-night ambush. Maximum discipline is called for; at times we would even control our breathing to avoid detection. One night as I lay in wait above a trail, I noticed little green flares flying in all directions—as if there were a noiseless firefight of tracer rounds. All of a sudden, one "tracer" flew directly at my face, almost in perfect line with my two wide-open eyeballs. I ducked. To my relief, the green light flew in slow motion over my helmet.

Later the guys asked me why I had been ducking and thrashing around the night before. They nearly died of laughter when I told them. Now I find out the fireflies were making love in front of our killing zone. If those fireflies had only known.

Vicente Rivera
Tucson, Arizona

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

By Stéphan Reebs

Naked: It's So 68,000 B.C.

One of the great questions for the fashion industry must be, When was clothing invented? Climate being what it is, body coverings could not have been long in coming after the loss of hominid fur, but the familiar paleontological clues aren't much use in pinning down either of those developments. Fossilized bones say nothing about external layers, and skin and clothes don't fossilize well. But Ralf Kittler, a geneticist now at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, Germany, and his colleagues haven't let such details stand in their way.

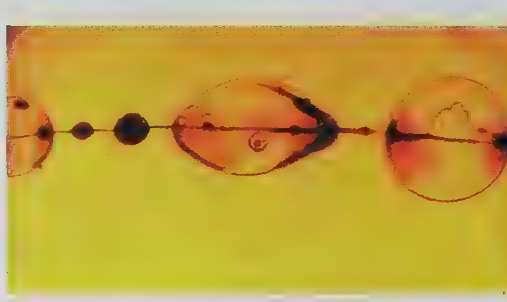
Body louse: a downside of clothing

The body louse *(Pediculus humanus corporis)*—an evolutionary offshoot of the head louse—munches on the skin but inhabits clothing. So Kittler and his team reasoned that by estimating when the body louse emerged as a separate subspecies they could estimate when wearing clothes became the normal thing to do. The team examined differences between parts of the genes of body lice and head lice. In addition, because human beings and chimpanzees went their separate ways 5.5 million years ago, the team compared the human louse sequences with the sequences of chimpanzee lice. The latter comparison made it possible to calibrate the rate of change in the genomes of the lice. On the basis of their estimates of those rates of genetic change, they calculated that the human body louse emerged as a species some 70,000 years ago—a time frame that coincides nicely with the spread of modern humans out of Africa and into colder climes.

Earlier estimates for the widespread use of clothing were based on artifacts. Bone needles have been dated to 40,000 years ago; statuettes and clay impressions attest to the variety of weaving techniques in Europe by 30,000 years ago. Fashion mavens, rejoice: the demise of nakedness is no longer completely cloaked in mystery. ("Molecular evolution of *Pediculus humanus* and the origin of clothing," *Current Biology* 13:1414–17, August 19, 2003)

Spinmeisters

You wouldn't think spider webs could be part of the fossil record—and if it weren't for the preservative power of amber, they wouldn't be. Scrutinizing a fragment of Lebanese amber 130 million years old, Samuel Zschokke, a biologist at the University of Basel in Switzerland, discovered a thread of spider silk a sixth of an inch long, studded with thirty-eight minuscule droplets of glue. Both the diameter of the thread and the size, shape, and arrangement of the droplets are nearly identical to those of modern web-weaving spiders.



Sticky spider silk in amber, magnified 150 diameters

The specimen, whose true identity had remained unrecognized since 1969, came from the world's oldest deposits of amber containing insect remains. Fossilized spinnerets (the organs that spit out the spider silk) that occur in Middle Devonian rocks in Schoharie County, New York, show that spiders have been making silk for at least 380 million years. But there's no evidence that the threads made by those ancient spinnerets were gluey. Zschokke's discovery thus establishes the earliest time that spider webs became sticky. ("Spider-web silk from the Early Cretaceous," *Nature* 424:636–37; August 7, 2003)

Poisoning the Waters

Algae are a diverse crew. They range from single cells less than one ten-thousandth of an inch across to gigantic organisms hundreds of feet long. They're also the mainstay of the marine food chain, but that doesn't mean they passively accept their status as food. Certain microalgae actively emit toxins, and recent investigations show the toxins may have an offensive as well as a defensive role. Marine biologists Alf Skovgaard of the Institute of Marine Sciences in Barcelona, Spain, and Per Juel Hansen of the University of Copenhagen now have hard evidence that toxins from the microalga *Prymnesium parvum* may ward off competitors or even help the algae procure lunch.

Marine biologists have long believed that algal toxins repel would-be predators, such as fish and crustaceans. And it is well known that when algae proliferate, their toxic blooms can wipe out a region's aquaculture or close down its seafood restaurants. *P. parvum*—a notorious source of toxic blooms worldwide—photosynthesizes like a plant, but it also has animal ambitions: the creature ingests prey, sidling up to other microorganisms and engulfing them. But that process works well only with prey that aren't mobile: single-celled algae, after all, have no limbs or mouthparts to catch and hold their next meal. *P. parvum*'s way around that limitation is to secrete chemical stun guns.

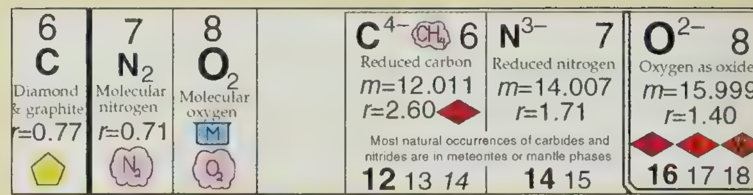
Skovgaard and Hansen have shown that the higher the concentration of *P. parvum* secretions, the more the motile microorganisms become immobilized and the more *P. parvum* move in to feed on them. And besides helping to provide meals, toxins could be disabling competitors and predators. In fact, the multifaceted function of toxins could contribute to the alga's periodic, and destructive, population explosions. ("Food uptake in the harmful alga *Prymnesium parvum* mediated by excreted toxins," *Limnology and Oceanography* 48:1161–66, May 2003)

Elemental Question

When attention wanders in science class, students' eyes often scan a familiar wall adornment: the periodic table of the elements. But if L. Bruce Railsback has his way, that enormous but relatively simple chart will be replaced—at least in earth-sciences classrooms—by a far more complex table.

Railsback, a geologist at the University of Georgia, in Athens, notes that the now-standard version of the periodic table, formulated in Europe in the 1860s, is of little use to earth scientists. It lines up only the pure elements. In nature, though, elements usually occur as ions—that is, in a charged form, often as part of compounds such as salt.

So Railsback has rearranged the elements as ions, not hesitating to revise the "sacred" text of chemistry by repeating elements that commonly occur as different ions, with different electric charges, under different conditions. The rearrangement has the advantage of grouping the ions on the basis of the kinds of combinations in which they often occur. Railsback also depicts interrelations via such devices as color (green for nutrients essential to life, red-brown for ions that make oxide minerals, and so on); size and boldness of the labels, which correspond to the abundance of the ion; and a host of symbols to indicate which minerals an ion forms.



Ions get a place at the geologist's new periodic table.

The result is a visually striking, information-packed chart that goes a long way toward explaining geochemical processes and patterns of abundance in the Earth's crust, mantle, and oceans. A patient student can now make better sense of why certain elements are more soluble than others (and thus more likely to occur in the sea), or why gold doesn't rust. But such a student will need more time to read the elaborate chart than most boring classes will ever afford. ("An earth scientist's periodic table of the elements and their ions," *Geology* 31:737–40, September 2003; www.gly.uga.edu/railsback/PT.html)

Really Sinister

What did Julius Caesar, Marilyn Monroe, Ronald Reagan, and Babe Ruth have in common? If you said all of them were lefties, smile and take a bow. Favoring the use of one side of the body isn't unique to people, though: some cats tend to reach with their left paws, for instance. Nor is the trait restricted to the use of limbs: some fishes tend to use the left eye to check out members of their own species.

But a left-handed snake? Well, yes: when snakes are at rest, they coil their bodies, and that puts one side or the other on the inside of the coil. According to Eric D. Roth, a herpetologist at the University of Oklahoma in Norman, if an individual snake or a species coils one way or the other in a reasonably consistent way, it makes sense to call the behavior "handedness."

Cottonmouth coiling (most of the way) with its left side on the inside

Roth recently spent six months repeatedly noting the coiling configuration of twenty adult cottonmouths, a venomous species native to the southeastern United States. Sixteen of the cottonmouths coiled more often with the left side of the body on the inside of the coil. Roth considered the effect strong enough to regard the population as "left-handed." Among the sixteen lefties, three were southpaws at the individual level: they coiled to the left twice as often as they coiled to the right—too marked a tendency to be caused by chance alone.

Does the frequency of handedness—or, more generally, "behavioral lateralization"—in lower vertebrates suggest that the animal brain became lateralized early in vertebrate evolution? It's too soon to tell. But it is safe to say that the idea of a left-handed snake isn't just a put-on. ("'Handedness' in snakes? Lateralization of coiling behaviour in a cottonmouth, *Agkistrodon piscivorus leucostoma*, population," *Animal Behaviour* 66:337–41, August 2003)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

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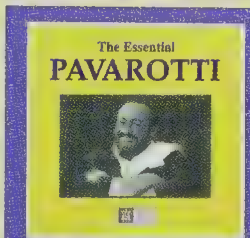

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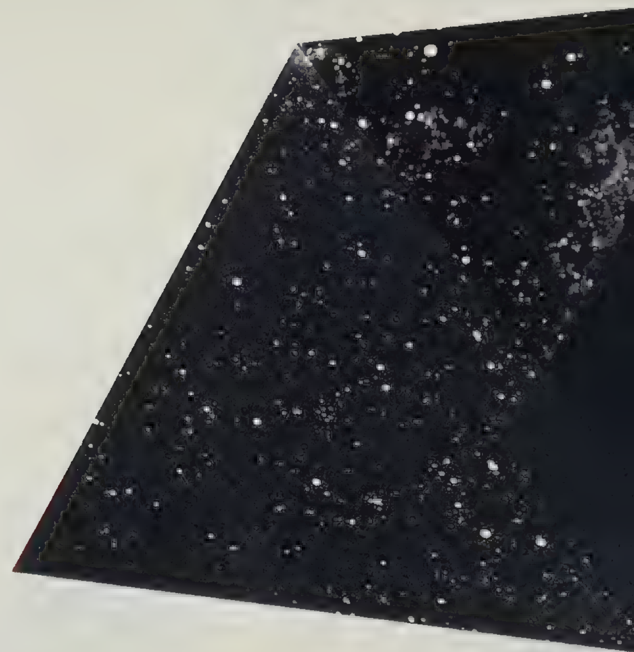
Dark and Darker

There's a lot more gravity in the cosmos than meets the eye.

By Neil deGrasse Tyson



Gravity, that most familiar of nature's forces, is both the best- and least-understood phenomenon in the cosmos. Not until Sir Isaac Newton turned his attention to the problem in the late seventeenth century did anybody figure out that gravity's mysterious "action at a distance" is caused by matter. Newton was the first to realize that a simple algebraic equation could describe the gravitational attraction between any two bodies, and that from that equation you could "weigh" the Earth and predict the future orbits of the planets. And not until Albert Einstein pondered gravity in the early twentieth century did anyone figure out that action at a distance is better understood as a warp of space-time, caused by the presence of matter or energy or both.

Neither Newton nor Einstein thought he was describing anything other than ordinary matter, the kind you can see, touch, feel, and taste. Yet for nearly three-quarters of a century astrophysicists have been waiting for someone to explain why 85 percent of all the gravity in the universe originates in a substance that no one has ever seen, touched, felt, or tasted. There's no guarantee that it even *is* a substance: maybe "excess" gravity emanates from something other than matter. In any event, the experts are clueless—and no closer to an answer today than they were in the 1930s. That's when the colorfully contentious Swiss-American astrophysicist Fritz Zwicky discovered the first sign that there is far more gravity in the cosmos than the stars, galaxies, and other visible objects could ever account for. Where was the "missing mass"?

Zwicky had been studying the Coma cluster, a titanic ensemble of galaxies far beyond the local stars that trace the constellation Coma Berenices (a Latin phrase meaning "hair of Berenice," in honor of an ancient Egyptian queen who willingly cut off her tresses). Isolated and richly populated, the Coma cluster lies more than 300 million light-years from Earth. Thousands of galaxies revolve about its center, moving in every possible orbit like bees circling a beehive.

The dark matter in the universe is six times more common, on average, than ordinary matter.

By measuring the motion of a few dozen galaxies, Zwicky discovered that their average speed is astonishingly high—much too high for the gravity field exerted by all of the Coma cluster's visible matter to be holding the cluster together. By all rights, the galaxies he observed ought to have been flung off into deep space—yet they clearly seemed bound by gravity to the rest of the Coma cluster. Some matter—at least some source of gravity—seemed to be misbehaving.

Zwicky based his conclusion on an intimate relation between the total amount of matter in a galaxy cluster and the observed speeds of its orbiting member galaxies. Assuming the cluster is not in some odd state of expansion or collapse, if you know the size of the cluster, and if you can estimate its mass, you can invoke Newton's equation to calculate what the orbital speed of its galaxies should be.

You can do a similar calculation for the orbital speed of each planet in the solar system. All you need to know is the planet's mass, the Sun's mass, and the distance between the two—well-known quantities by now. Calculate what the orbital speed of the Earth should be, and then measure the actual speed. The two figures will agree. But suppose you measured Earth's speed and it came out ten

Rupert Deese, *Swimmer,* 1988

times greater than Newton's laws said it should be. Knowing that Earth's velocity of escape from the solar system is only one-sixth that figure, you'd have to wonder why Earth (and all the other planets) hadn't flown the coop long ago.

In the Coma cluster, Zwicky found, galaxies were traveling faster than the escape velocity he calculated for them. Hence the cluster should have flung itself apart within several hundred million years of its birth, leaving barely a trace of its existence. Yet Coma's symmetrical beehive shape bespeaks an age perhaps as venerable as that of the universe itself.

In the decades that followed Zwicky's discovery, other galaxy clusters were found to have the same pattern. That meant no one could dismiss the Coma cluster as a renegade, and the significance of the problem became correspondingly magnified. Who—or what—was to blame? Newton? Not likely. His theory had survived two and a half centuries of testing. Einstein? Nope. Even the formidable gravity operating within galaxy clusters is too weak to require the corrective treatment of Einstein's general relativity. Perhaps the absent mass was just ordinary matter that happened to be dark—burned-out stars, for instance, that were no longer emitting visible light. For a short time, in fact, investigators named the problem "missing light" rather than "missing mass." But even when astrophysicists realized that the true problem was surplus gravity, they hurried to invent its presumed source, bestowing upon it the spooky name "dark matter."

Just as astrophysicists were growing accustomed to their ignorance, the problem of dark matter reared its invisible head somewhere else. During the 1970s and 1980s Vera Rubin, an astronomer at the Carnegie Institution of Washington in Washington, D.C., and her colleagues discovered that individual spiral galaxies present a similar anomaly. Beyond the luminous disk of such galaxies, scattered across the largely empty, "rural" areas of the cosmos, are a few gas clouds and isolated regions where bright stars are being born. By observing such star-forming regions, Rubin could trace the gravity field beyond the galaxy's visible edge. If those regions and gas clouds were subject only to the gravity of the visible matter in the galactic disk, their orbital speeds out there in Nowheresville should have dropped. But Rubin discovered that their speeds stayed high, without a trace of dropping off, even in the most remote locations.

Things that make you go hmmm.

If there isn't enough visible matter in the outer zone to account for the sustained orbital speeds of the tracer stars, she reasoned, there must also be some form of dark matter out there. Something was creating enough gravity to prevent the expected drop-off in speed. It turns out that the "extra" gravity, which astrophysicists came to call a dark-matter halo, extends outward to at least ten times the radius of every spiral galaxy ever observed.

Ordinary matter and dark matter loosely track each other in space, but not in a one-to-one ratio. Averaged across the entire universe, cosmic dark matter "outweighs" visible matter by a factor of six. But the ratio varies substantially from one kind of astrophysical environment to another. Dark matter is most dominant in large entities such as galaxy clusters, and unmeasurable in small entities such as planets. The surface gravity of Earth, for instance, can be accounted for entirely by the ordinary matter that's under your feet. So don't try to blame dark matter if you're overweight.

That variation in ratios is a sure sign that dark matter distributes itself more diffusely than ordinary matter. Otherwise, six pieces of dark matter would be clinging to every chunk of ordinary matter. As far as anyone can tell,

though, that's not the way things are. Given the six-to-one ratio, all the ordinary, recognizable matter in the universe—the stuff you and I are made of—amounts to no more than a minor ingredient in the birth, evolution, and fate of the cosmos. Get over it.

Best as astrophysicists can figure, dark matter isn't just matter that happens to be dark; it's something else altogether. Yes, it wields gravity, but it doesn't do much else that's familiar. It neither absorbs nor emits light, rendering telescopes practically useless. And so a big, basic question remains unanswered: If all matter has mass, and all mass has gravity, does all gravity have matter?

How can we be sure dark matter isn't simply matter that happens to be dark? Investigators examined all the plausible candidates—as if they were looking over the suspects in a police lineup. Is it made of black holes that come from stars? No, theories of stellar evolution rule out that possibility, and besides, such a huge quantity of black holes would have shown up in other ways. Is it dark clouds of gas? No, they would absorb or otherwise interact with light from the stars behind them, which genuine dark matter doesn't do. Is it interstellar or intergalactic planets, asteroids, or comets, all of which emit no light of their own? Seems unlikely: it's hard to believe the universe would lock up six times as much mass in planets as it does in stars. If it had, there would be 6,000 Jupiters for every Sun, or even less likely, 2 million Earths per Sun. But in our own solar system—if that's a typical example—the mass of everything other than the Sun adds up to less than two-tenths of 1 percent of the solar mass.

When nothing else works, scientists sometimes question the foundations of their assumptions. In the early 1980s the physicist Mordehai Milgrom of the Weizmann Institute of Science in Rehovot, Israel, proposed a new twist to Newton's law of gravity: modified Newtonian dynamics, affectionately called MOND. Admitting that standard Newtonian dynamics works just fine on the scale of stars and planets, Milgrom suggested that Newton needed help at the scale of galaxies and galaxy clusters. His solution was to add a term to Newton's equation—a term mathematically rigged to come to life only when applied to great distances. Although the term was intended primarily as a computational tool, Milgrom didn't rule out the possibility that it referred to an unheralded phenomenon of nature.

MOND enjoyed some success describing isolated spiral galaxies, but it was not conceived as a complete theory of gravity, and so it lacks a mechanism for calculating the motions of more complex systems, such as multiple galaxies. More important, MOND jumps through hoops to say anything about the early universe, where galaxies had not yet formed. In early 2003 NASA published a portrait of the cosmic microwave background made by the Wilkinson Microwave Anisotropy Probe (WMAP); that image, combined with data from other telescopes, isolated and measured the effects of dark matter in the early universe—leaving MOND with nothing to contribute, awaiting a likely burial in the graveyard of creative but wrong ideas.

"Dark matter" wields gravity, all right, but no one knows whether it's really matter at all.

Dark matter, though mysterious, has quite real effects, and helps demystify many phenomena that would otherwise go unexplained. By the time the universe was half a million years old, matter had begun to coalesce into the blobs that later became galaxy clusters and superclusters; during its next half million years the universe grew by 50 percent. All the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while, two competing efforts were at work: gravity was trying to collect and concentrate matter; cosmic expansion was trying to dilute it. When you do the math, you rapidly conclude that the gravity of ordinary matter could not have won the battle on its own. It needed help, and that help came from the gravity of dark matter. Without dark matter the universe would have no structures: no galaxies, no stars, no planets, no astrophysicists. How much extra gravity did ordinary matter need? Six times as much as it could provide on its own.

Dark matter played another crucial role a couple of minutes after the big bang, when the universe was dense and fiery, and protons began to form hydrogen nuclei. Within that cosmic crucible, other atomic nuclei were soon forged by nuclear fusion: significant quantities of helium, as well as minute quantities of deuterium (which is hydrogen with a neutron added to the nucleus) and lithium.

Of the four forces of nature, the strong nuclear force—the one that packs protons and neutrons together to form nuclei—was the prime mover back then. By the time the temperature dropped below the threshold for fusion, one in ten nuclei in the universe had become helium, one in a hundred thousand deuterium, and one in 5 billion lithium. The rest—about 90 percent of all nuclei—remained hydrogen.

What if all the dark matter during the first few minutes after the big bang had been dark ordinary matter? Six times as many interactive particles would have been squeezed into the infant universe. That huge extra quantity of ordinary matter, gung-ho as it was for fusion, would have dramatically pumped up the fusion rate of hydrogen but would have consumed much of the deuterium in the process.

As it happens, all the deuterium in the cosmos was manufactured immediately after the big bang. And because deuterium is readily consumed in the cores of stars, the most unevolved regions of the cosmos should hold no more of the stuff than existed at the end of the fusion era, after the first few minutes of the universe. And sure enough, the spectra of galaxies whose gas clouds have been only minimally processed show one deuterium atom in every hundred thousand. Just what one would expect from a big-bang birthday suit wrapped in a dark-matter blanket.

Without dark matter the universe would have no galaxies, no stars, no planets, no astrophysicists.

Astrophysicists are generally reluctant to base calculations on things they don't understand. Unrelenting skeptics will surely compare the dark matter of today with the hypothetical, now-defunct "luminiferous aether" that generations of physicists had proposed as the carrier of light waves. But dark-matter ignorance is fundamentally different from aether ignorance. Whereas the aether was a cover for scientific cluelessness, dark matter is not merely presumed to exist. Its gravity has been shown to exist. No one is pulling it out of thin space. In fact, dark matter is no less real than the hundred-plus planets now known to orbit stars other than the Sun—planets discovered solely by the effects of their gravity on their central star.

Other unrelenting skeptics might declare, "Seeing is believing." That premise may make you a good carpenter or cook or resident of Missouri, but it won't make you a good physicist. Physics is not about seeing; it's about measuring—preferably with something that's not your own eyes, which are inextricably conjoined with the baggage of your brain.

Having resisted all attempts to understand it, dark matter has become a kind of Rorschach test for investigators. Gravity skeptics say we don't really understand gravity. Particle physicists say dark matter could be some ghostly class of undiscovered particle. Maybe the particles interact through gravity plus some unknown additional force, or maybe (and more likely) they do respond to normal forces, but so weakly that the particles are virtually undetectable. Or how about the cosmic exotica that sometimes appear in "theories of everything"? Perhaps a parallel, phantom universe exists right next to ours, revealed only through its gravity. We'll never actually run into its matter, but we might feel its tug.

Whatever dark matter is, though, its effects in the contemporary universe are straightforward enough to calculate. It doesn't appear to interact through the strong force, so it can't make nuclei. It doesn't interact through the weak force, so its particles don't decay into lighter ones. It doesn't interact through the electromagnetic force, so it doesn't make molecules, nor does it absorb, emit, reflect, or otherwise scatter light. It exerts gravity that ordinary matter responds to. End of story. Beginning of ignorance.

But so far as anyone knows, the march of astrophysics hasn't yet been derailed or stymied by that bit of uncertainty. We astrophysicists don't happen to know what the stuff is. Nevertheless, we carry it along as a strange friend, and invoke it wherever and whenever the universe demands. And by doing so, we get all the right answers—except to the question that matters most.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City. Videotapes of a dozen of his lectures, under the title "My Favorite Universe," were recently released by the Teaching Company (www.teachco.com). *All twelve are based on essays that have appeared in* Natural History.

Photos: Cayman Islands Department of Tourism

The Cayman Islands

South of Cuba, the Caymans consist of a trio of islands: Grand Cayman, Cayman Brac, and Little Cayman. All are renowned for their spectacular coral reefs, sun-kissed beaches, waters teeming with fish flecked with gold, and a grand 500 years of culture, history, and beauty.

The best known island is Grand Cayman, a great place to start your adventure. George Town, the capital city, boasts some of the finest cuisine and shopping in the Caribbean, and you can also explore the islands' rich history here. In addition to world-class scuba diving, snorkeling, and sailing, plan a trip under the sea to feed the stingrays, an excursion to the Turtle Farm, or a journey into the past to revisit the first landing by Christopher Columbus. If you're interested in natural history, make sure to visit the sixty-five-acre Queen Elizabeth II Botanic Park and the National Trust's Mastic Trail. This two-mile footpath through unspoiled woodlands guides you through Grand Cayman's largest area of untouched, old growth dry forest—among the last remaining examples of the Caribbean's dry, subtropical forest.

The "Sister Islands," Cayman Brac and Little Cayman, will relax you with their unique Caribbean lifestyle. Walk, hike, bike, take a leisurely drive, or just enjoy the blissful solitude. Just twelve miles long and two miles wide, Cayman Brac is famous for its superb diving and snorkeling. Its sloping, vertical walls as well as shallow sites burst with coral growth. The Brac also is home to over 200 bird species and is a stopping-off place for many birds on their way to warmer weather.

And just eight miles east of Cayman Brac lies Little Cayman. Still mostly undeveloped, Little Cayman has a population of less than 100 and is a nature lover's paradise. Explore its sandy beaches and coastline, lagoons, mangrove forests, salt ponds, and wetlands speckled with orchids. The birding here is outstanding. Among the must-visit stops is the Booby Pond Nature Reserve, with the largest red-footed booby colony in the Caribbean—more than 20,000 birds. There are nature sites with viewing platforms overlooking wild iguanas, egrets, West Indian whistling ducks, and many other birds.


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CAYMAN ISLANDS

Distinctive Destinations

Maryland

Photos: Middleton Evans/Maryland Dept. of Tourism

If you're looking for a perfect getaway that has a bit of everything—history, culture, and the great outdoors—then Maryland is the answer.

Nature lovers might start their visit in the state's Western Region, home of Deep Creek Lake, rushing waterfalls, and a portion of the Appalachian Trail. Here you'll find the rugged Allegheny Mountains, and Maryland's tallest mountain, Backbone. Civil War buffs won't want to miss the Antietam National Battlefield, site of the bloodiest single-day battle of the war. In the Southern Region, plan some time for birding: Charles County alone has 321 species of birds, including bald eagles, and miles of marshes teeming with wildlife. Charles also is a center of early Maryland history. Visit the Maryland Indian Cultural Center, in Waldorf, to learn about Native American life before European contact, and the Afro-American Heritage Society, in LaPlata, which depicts the history of African Americans in Charles County. In the Capital Region, near Washington, D.C., learn about space travel at NASA Goddard Space Flight Center. In the Central Region, visit Baltimore, the state's largest city, known for its cultural attractions as well as its famed Inner Harbor. Don't miss the Harbor's renowned National Aquarium, which houses sharks, dolphins, sea turtles, and thousands of other aquatic animals. Maryland's lovely capital city, Annapolis, is also America's sailing capital. With more eighteenth-century edifices than any other city in the U.S., this historic town is still an important maritime center.

And finally, take a drive through the fragile and beautiful Eastern Shore, between the Chesapeake Bay and the Atlantic Ocean. Enjoy the sandy beaches and boardwalk of Ocean City, a year-round resort. Just south of Ocean City, wild ponies roam the beaches and dunes of Assateague Island National Seashore. According to one legend, the ponies on this 37-mile-long barrier island are descendants of horses that survived the shipwreck of a Spanish galleon. Anywhere you go in Maryland, you can have a delectable meal of a just-caught fish, or perhaps some freshly shucked oysters, or the state's famous blue crabs, prepared in a multitude of delicious ways.

With so many things to do, so close together, Maryland will appeal to every taste.


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West Virginia

West Virginia is Wild and Wonderful, says the state's slogan. This is no idle boast: 80 percent of the state is forested. No wonder, then, that there are great opportunities for camping, hiking, and more: Paddling through frothing rapids. Mountain biking down steep tracks. Scaling sheer cliffs. Horseback riding in forests teeming with wildlife. Or making the perfect cast to tempt an elusive trout or bass. Take it outdoors—in West Virginia.

A salt desert in the Bolsón de Pipanaco, an enclosed basin in northern Argentina, is home to a rare species of rodent. The animals dig their tunnels in some of the natural mounds that pepper the landscape. Fresh tracks provide good clues to the whereabouts of the tunnels' occupants.

Desert Dreams

Seeking the secret mammals of the salt pans

By Michael A. Mares

On several forays into the Salinas Grandes—one of Argentina's great salt deserts—we had dug up mysterious burrows, but we had never discovered what kind of animal made them. Our team of biologists was looking for a rare mammal, a salt-pan specialist with a store of unique genetic information. Our failure was like a weight I carried with me every day. The bad news, I told my three co-workers, was that we would go back one more time. There were groans; it was a long, hard field trip. The good news, I said, was that we wouldn't dig anymore. Moving tons of earth had already proved to be no way to find our quarry, presumed to be a rodent.

The year before, I had brought some Conibear traps to Argentina, spring-loaded traps (named for their inventor, Frank Conibear) that can seize and kill animals without the need for bait. The problem had been figuring out where to place the traps so that animals would step into them. I had never been able to catch anything in Conibear traps before, but now I pinned my hopes on them. "There must be some reason I carted them down here," I told myself.

Back we went, to the Gran Chaco area of Central Argentina, the road by now familiar, and made camp. That first day I spread out my two dozen Conibear traps, while the others set our standard array of baited traps. There was nothing to do now but wait. In the frigid winter night, I dreamed that a new, rare, salt-desert rodent got caught in one of my traps. In my dream, though, the animal was dragged away by a predator before I could get to it. The thought jolted me wide-awake. It was 3:00 A.M., and the Sun wouldn't be up for hours. The cold stillness hardly beckoned me out of my sleeping bag. I rationalized: How could I find the trap in the dark, anyway? I decided to wait for dawn.

Salt deserts or salt pans—"salinas" in Latin America—are among the most extreme habitats on Earth. In some cases they formed where ancient seas once intruded on the land, then retreated and evaporated, leaving crystalline salts—mainly sodium chloride—behind. In other areas, where arid mountains surrounded enclosed basins, salts weathered from the uplands by seasonal precipitation were carried with the runoff into the valley below; again, when the water evaporated, the salts remained. But in whatever way the salts accumulated, eventually they covered the soil with a blindingly white patina. Few species, plant or animal, can survive in the forbidding habitat.

Among the exceptions are certain halophytic, or salt-tolerant, plant species in the goosefoot family (the Chenopodiaceae, or chenopods), which thrive in hot salt deserts throughout the world. The salt concentrations in the stems and leaves of these plants are many times what they are in seawater; the salts keep precious fluids in the plants' cells from being drawn by osmotic pressure into the salty soil. At the same time, as the water in their cells evaporates, the plants must prevent their internal salt concentrations from getting too high. Many halophytes compensate for evaporation by depositing salt crystals on the surfaces of their leaves, giving the leaves a grayish silver cast.

Halophytic chenopods, such as saltbushes, are green throughout the year, and their lush color might mislead one into thinking they are an ideal food source for plant-eating mammals. In fact, almost no mammals can process

the high concentrations of salts. In three widely separated deserts, however, a few remarkable exceptions have been discovered, some only quite recently. All the species are rodents that have evolved highly specialized features to overcome the challenge of surviving on the salt-filled vegetation of the salt pans.

The first such species to be discovered was the chisel-toothed kangaroo rat *(Dipodomys microps)*. Kangaroo rats belong to a North American family of rodents well known for living in arid habitats, where they forage almost exclusively for seeds. They seldom have access to drinking water, but instead get most of their moisture from digesting the seeds.

Even among kangaroo rats, though, the chisel-toothed species is unusual. Unlike other species in the family, which have pointed upper and lower incisors, the upper incisors of *D. microps* have a broad cutting edge, and the lower incisors have the bladelike profile of a wood chisel. Investigators who studied the animal in the Great Basin Desert of the western United States in the 1970s discovered that it scrapes saltbush leaves against the lower incisors, thereby peeling away the crystalline layer of salt. The succulent green leaf tissues that remain still contain high levels of salt, but the rat's specialized kidneys produce a highly concentrated urine that removes those salts. Those adaptations enable the rodent to rely on the evergreen saltbush plants for sustenance throughout the year. But for many years ecologists thought it was the only mammal to have solved the riddle of living on the poisonous saltbush.

Chisel-toothed kangaroo rat (Dipodomys microps) *survives on a diet of salt-loving desert plants in the Great Basin Desert of the western United States. It was the first mammal discovered that could cope with such salty food in the absence of a source of freshwater.*

Then, in the 1980s, biologists began to study another desert denizen, the fat sand rat *(Psammomys obesus)* of the northern Sahara. The species belongs to the same family as the house mouse and the Norway and black rats, but it is only distantly related to the kangaroo rat. Even the basic body forms of the two desert rodents underscore the remoteness of their evolutionary kinship. The kangaroo rat has long hind legs on which it hops—a bit like its Australian namesake in miniature. The fat sand rat looks more like a gerbil. Yet, just like the chisel-toothed kangaroo rat, the fat sand rat inhabits saltbush areas in a desert; it feeds on the saltbush; it scrapes salt crystals from leaves with its lower incisors; and its kidneys excrete a highly concentrated urine. Having embarked long ago on distinct evolutionary journeys in widely separated arid areas of the planet, the two species have converged in certain remarkable details of their anatomy, physiology, behavior, and ecology.

The two saltbush-eating species remained the only ones known to science until the 1990s. But in 1995 I was able to determine that there is a third species, native to a third desert habitat: the Argentine Monte. I had first worked in this biogeographical region, a 1,200-mile-long strip of western Argentina, in the 1970s, when I studied the evolution of the mammals of the Monte. On one of my field trips, I had hoped to find a little-known rodent called the plains, or red, viscacha rat *(Tympanoctomys barrerae)*. The species was known to be a ratlike creature with a somewhat bushy-tipped tail, which presumably lived in saltbush areas near salt flats. It had been classified among the Octodontidae, a family of rodents that has inhabited South America for tens of millions of years. But the plains viscacha rat had not been found again in four decades, and only a few museum specimens were available for study.

My own search in the 1970s came up short, but in the late 1980s my former student, Ricardo Ojeda, an Argentine desert biologist working for the Institute of Arid Zone Studies (IADIZA) in Mendoza city, and several Chilean colleagues, finally collected some live specimens of the elusive animal. In the decades that had passed since the species had first been captured, scientific techniques had entered the era of genomics. The investigators discovered that the plains viscacha rat has 102 pairs of chromosomes, the highest number then known for a mammal. At the time, the nearest known relative of the plains viscacha rat was another viscacha rat, *Octomys mimax*, with fifty-six chromosomes.

In the mid-1990s, working in the Monte desert with Janet Braun, a colleague at the Sam Noble Oklahoma Museum of Natural History in Norman, and Robert B. Channell, then a graduate student at the University of Oklahoma and now of Fort Hays State University in Kansas, I was finally able to capture several plains viscacha rats

alive. We learned that they make their homes in mounds largely formed through soil erosion and deposition. The mounds afford protection from the floodwaters that arise each summer, when monsoonlike rains and runoff water from the surrounding mountains inundate the parched salt flats. A typical mound is thirty feet long, ten feet wide, and three feet high, with as many as thirty openings and burrows at three different levels, perhaps dug over more than one generation. Sometimes several mounds lie close together. Surprisingly, however, each mound or set of mounds houses only one plains viscacha rat.

We examined a captive animal in a terrarium, where I fed it samples of the plants that grow on the mounds. It refused to feed on most of them, but when saltbush was offered, the creature quickly gobbled up the gray-green leaves. I noticed that as it held the plant in its forepaws, it rapidly moved its face and mouth, so that at times they appeared to vibrate. Bits of plant tissue flew aside, some sticking to the glass walls of the terrarium.

As I gathered up the bits, I was astonished to find that they were the salt covering of the leaves. How did the rodent manage to strip the salt from the leaves so quickly? I examined its mouth. Not too surprisingly, it had broad upper incisors and chisel-shaped lower incisors. But remarkably, in the soft tissue of the mouth, the animal appeared to have an extra pair of upper incisors, something no one had noticed while preparing the few museum specimens.

Examining these structures with a hand lens (and later with a light microscope and an electron microscope), I found that the extra "teeth" are actually stiffened bristles of hair [*see photomicrograph on page 32*]. The bristles are gathered into bundles that not only look like teeth, but are also sharpened against the tips of the lower incisors, much the way the true upper incisors are. (Both upper and lower incisors continue growing throughout the animal's life.) Hence for all practical purposes, the rodent has three sets of incisors with which to deal with the salt-encrusted leaves. And like the North American kangaroo rat and the North African fat sand rat, the South American plains viscacha rat also proved to have kidneys that produce highly concentrated urine.

After our work with the plains viscacha rat, I became convinced that the vast salt flats scattered throughout the deserts and arid thorn forests of northern Argentina could harbor other salt-pan specialists. In 1999, along with Rubén Barquez of the National University of Tucumán in Argentina, Mónica Díaz of Texas Tech University in Lubbock, and Braun, I traveled to a salt desert within the Bolsón de Pipanaco, in Catamarca Province, Argentina. An enclosed basin that runs 120 miles from north to south, and as wide as 80 miles, the Bolsón de Pipanaco appeared to be just the kind of place where another octodontid might have become isolated sometime in the past 15 million years, as the Andean mountain chains were uplifted.

Saltbushes—such as this Atriplex canescens, which ranges from northern Mexico to southern Canada—excrete excess salt onto their leaves. The salt crystals that form not only discourage consumption by herbivores, but may also help protect the plants from the intense sunlight.

After crossing through dense desert woodland with large, thorny mesquite trees, we entered the salt flat and began to search for telltale mounds that might belong to our hypothetical rodent. Within half an hour we had found mounds riddled with tunnels that looked unlike the mounds of any species we were familiar with. Tellingly, the only vegetation growing on or near them was a halophytic chenopod, *Heterostachys ritteriana*. The plant lacked the broad, grayish leaves of saltbush; instead, the leaves were compressed into small bluish green balls, only slightly larger than BBs. But when I tasted them, they were extremely salty, and the leaves had obviously been cropped by a rodent.

The mounds occurred in clusters of as many as six, and the larger mounds were connected to several smaller ones. Each was about twelve feet by six feet—somewhat smaller than the mounds of the plains viscacha rat—and had many openings. A few were covered with fresh rodent tracks. We grabbed our shovels and began to dig.

Our customary tactic was to plug the burrow openings with live traps (boxlike traps with a door that swings shut when an animal enters, thus capturing the animal alive), expecting to catch the animal as it raced away from the mound in panic. We found burrows at several levels, with many intersecting passages and large chambers at the intersections.

We would follow a tunnel from the central part of the mound to the trap we had placed at the exit. As each tunnel was opened and cleared, we would move on to the next. But after opening an entire cluster—and moving half a ton of soil—we had found nothing. We began to excavate a second cluster. We uncovered food stores and latrines, but no traps slammed shut. There were about thirty tunnels in the mound complex, some as deep as three feet underground and snaking

among the tough roots of the salt plants. Finally only a single tunnel remained. If an animal occupied the cluster at all, it had to be here.

All of us were on high alert, waiting for it to run into the last trap. We cleared away the final bit of tunnel. Then: Nothing. Our hopes were dashed. We stared at the sand as if willing an animal to appear. Suddenly Janet screamed, "There it is!" We watched transfixed as a large golden rodent with a bright red bushy tail sprang from the sand and tried to escape. Mónica dove on the animal and grabbed it. It was beautiful. We all leaped with joy and hugged one another. We had found it! As we examined our prize it seemed obvious that it belonged to no genus and species that had ever before been described. But it was, indeed, an octodontid.

Bundle of bristles (left), here shown fifteen times natural size, is one of a pair of such bundles on the mouth of the plains viscacha rat (Tympanoctomys barrerae) *of western Argentina (right). The bundles act as an extra pair of upper incisors, enabling the animal to quickly strip salt off the surface of saltbush leaves. The animal belongs to the rodent family Octodontidae, a group whose fossil record in South America extends back tens of millions of years. Such rare desert mammals embody ancient genetic lineages that are not preserved in the continent's biologically rich rainforests.*

We named our find the golden viscacha rat, *Pipanacoctomys aureus,* its genus reflecting the isolated valley where it lives and its species name highlighting its golden color. Like the plains viscacha rat, it has a pair of little toothlike brushes behind its upper incisors, but they are less pronounced and less stiff than they are in the plains species. The golden viscacha rat has ninety-two chromosomes. Because genetic analysis shows that this animal is the closest relative of the plains viscacha rat, the high number of chromosomes in the latter species no longer seems so anomalous.

The golden viscacha rat is an extremely rare species, occurring over less than ten square miles of salt desert. That gives it one of the most restricted ranges of any mammal.

Why bother at all with these few little rodents? To most people, their desert realms appear to be wastelands. In some ways, however, deserts have a more distinctive biodiversity than the much-touted tropical forests: In South America, for instance, more genera and families of mammals occur in the grasslands, scrublands, and deserts of the continent than live in the vast Amazonian rainforest. Numerous families of the continent's mammals are restricted to deserts, whereas only one or two mammalian families are restricted to the tropical forest proper.

It is hard for any organism to survive in extremely arid regions. When today's deserts began to form, often millions of years ago, some mammals colonized them and gradually evolved unique adaptations. With time those early colonists differentiated through natural selection into species, genera, and even families. Their tough descendants, which have few relatives outside the desert, are a store of unique genetic information.

Unfortunately, that heritage is imperiled throughout the world by such man-made factors as global climate change, agricultural biotechnology, overgrazing, habitat destruction, uncontrolled hunting, petroleum production, and urbanization. Even the isolated Bolsón de Pipanaco is not immune. Large parts of the region have been cleared to make way for olive groves and vineyards, crops that are being irrigated with so-called fossil water—underground aquifers that accumulated in ancient times. Eventually the water table of the valley will drop, the drainage pattern of the salt flat will change, and the plants that the golden viscacha rat depends on will disappear.

My story might have ended here, if I had not been so persistent in convincing my colleagues to try our luck again. That was how, during our year 2000 field season, we had come to the Salinas Grandes, to begin a survey of that 3,200-square-mile area within the thorn forest of central Argentina known as the Gran Chaco. And so, after my anxiety dream about losing a trapped rodent, I was up at first light to check my Conibear traps. As I approached the end of the trapline, I still had caught nothing. Only two traps remained. Then I saw it. The next-to-the-last trap held an animal—a viscacha rat, unlike any I had ever seen. My nightmare notwithstanding, no predator had robbed me of it while I slept!

In the past, we had saved something special to celebrate the discovery of a new species. Usually it was a bottle of champagne or fine wine, but even a can of hearts of palm would

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[illegible] this trip I had splurged on a bottle of exceptionally good Argentine wine, which I packed with care and kept from freezing or overheating. In the several weeks we had been on the road, the rest of our wine supply had been depleted, but I had not allowed anyone to open this special bottle. "If you want to drink the wine, you have to catch the mammal," I would say.

As I returned to camp in the cold light of dawn, I hid the rodent behind my back, hanging it from my belt. Janet was already up, making coffee. I put on a dejected look. "Catch anything?" she asked. "Nothing," I said. Rubén and Mónica emerged from their respective tents. "Nothing?" they asked. "Nothing," I said. The sun was peeking above the horizon, and the aroma of coffee and salt mingled in the damp air. I began to rummage through the food boxes.

"What are you looking for?" Janet and Mónica asked, knowing I can never find anything around camp. "I'm looking for that bottle of wine," I said. Everyone stopped and looked at me. They knew I had caught an animal, and that it had to be new to science: it would become a type specimen, the specimen that is needed for the first scientific description of any new species or genus.

"Get the wine!" I said.

We named the new genus *Salinoctomys,* "the octodontid rodent of the salt flat." The species name, *loschalchalerosorum,* honors the great Argentine folklore group, Los Chalchaleros, whose songs my crews had sung during thirty years of field research across Argentina. The musicians had announced they would retire in 2001, after singing together for fifty-two years. We felt that they had accompanied us on every trip; we even joked that some of their songs could be called "type locality" songs, because their lyrics mentioned so many places our field crews had collected type specimens. It seemed the most appropriate and permanent way for us to thank the musicians for all the enjoyment their music had given us.

We celebrated our good fortune by drinking that wonderful bottle of wine, but the joy of discovery was tinged with a hint of melancholy. Such a moment would likely never be repeated. We planned to explore other isolated valleys and equally isolated mountaintops—habitat islands at high and low elevations, each as ecologically distant from the others as the islands in a Pacific archipelago—but we doubted we would ever encounter such a pair of distinctively new animals again, much less deduce their existence beforehand using only inferences about the habitat.

Still, we take satisfaction in encountering other new or rare animals. The world still harbors many undiscovered mammals. Each time a new species is found we peel back another layer of mystery about the complex history of life on earth. Crisscrossing the complex terrain of northwest Argentina, our routes bisect the ancient paths of Incas, as well as the unexcavated ruins of desert peoples who lived a millennium before the Incas. We gasp for air as we climb above 15,000 feet, pop Tylenol like candy for headaches, suffer in the freezing Andean winds, and broil in the heat of lowland desert. It is hard work, to be sure, but we couldn't be happier.

Michael A. Mares, former director of the Sam Noble Oklahoma Museum of Natural History, is a research curator and professor at the University of Oklahoma in Norman. He is the author of A Desert Calling: Life in a Forbidding Landscape *(Harvard University Press, 2002).*

Golden viscacha rat (Pipanacoctomys aureus) *was discovered by the author and his colleagues in the Bolsón de Pipanaco. Here the animal nibbles on* Heterostachys [illegible] *a salt-tolerant plant.*

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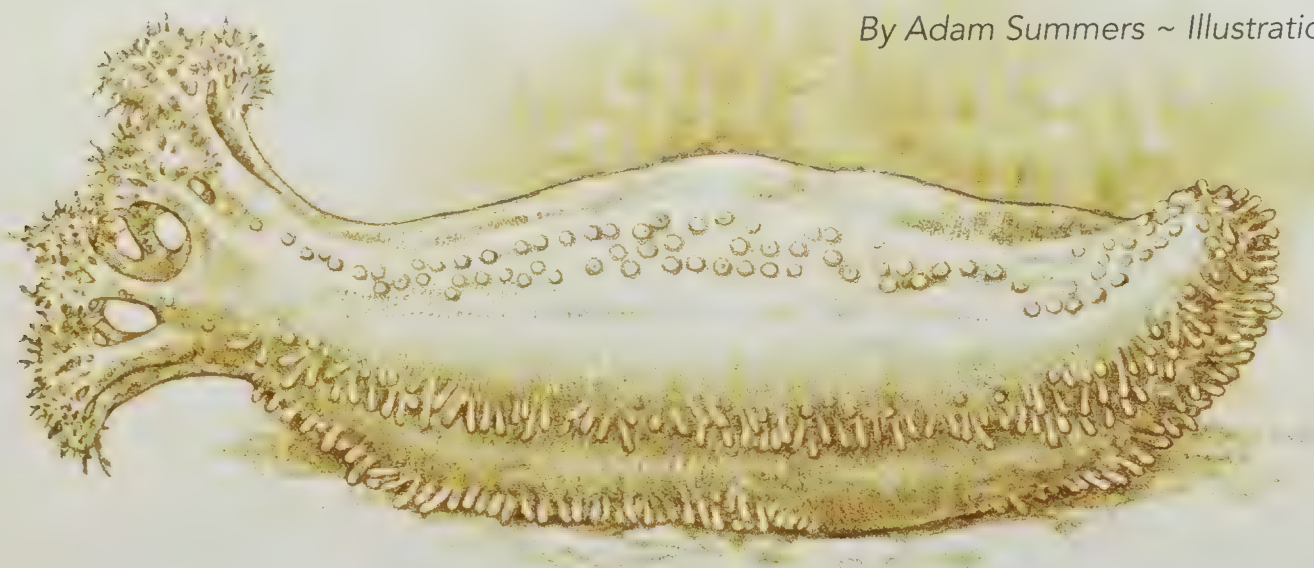
Catch and Release

Sea cucumbers might put a torn Achilles tendon back together again.

By Adam Summers ~ Illustration by Mick Ellison



North Atlantic sea cucumber, *Cucumaria frondosa*

When football season rolls around, a biomechanist's thoughts inevitably turn to connective tissue—and then, of course, to sea cucumbers. Most fans focus on cutbacks, open-field tackles and chop blocks, but I can't help but ponder the common casualties of these maneuvers: anterior cruciate ligaments (of the infamous ACL injury), hamstrings, and Achilles tendons. Anyone who has had to endure an injury in one of those body parts understands why they come to mind. Although tendons and ligaments—generally referred to as connective tissue—do stretch, they aren't nearly as elastic as rubber bands. In fact, they have a distressing tendency to tear or break, and when they do, they are devils to repair.

Sea cucumbers, invertebrate animals of the phylum Echinodermata, might hold out some hope for the afflicted. Although they have no internal skeleton, sea cucumbers and other echinoderms do have a kind of connective tissue, but one whose qualities are quite unlike those of mammalian ligaments and tendons. Biochemists and biomechanists are studying the stuff, known as catch connective tissue, because it might lead to new and dramatically superior repairs for injuries such as a running back's torn ACL.

Tendon is made up mostly of collagen, a protein that spontaneously aggregates into long, thin structures known as fibrils. The fibrils interact with each other and with their surroundings to form a stiff and cohesive tissue. But the process is apparently irreversible and non-renewable, and so if physical strain sunders the fibril bonds, tearing the tendon, it is impossible to reform them, at least in living tissue. The standard treatment is to tie the ruptured ends together and let scar tissue bridge the gap. But the bridge between fibrils is not terribly effective, and the scar tissue forms unwanted adhesions to other surrounding tissue. As a result, the tendon never regains more than about 60 percent of its original strength.

Imagine, then, the implications of an ointment that could cleanly break bonds between collagen fibrils and form new ones. A surgeon could chemically undo the rest of the bonds between two partially disjoined fibrils in the torn ends of a tendon, add fibrils to the gap at the frayed ends, and finally stabilize the repair by reestablishing the bonds between new and old fibrils and the rest of the tissue in the matrix: no gap, no scar, no loss of strength.

The armchair anatomist would be hard-pressed to find similarities between a sea cucumber and any part of a quarterback . Lacking arms, legs, and head, the brown cuke looks more like a football than a football player. Without an internal skeleton,

it has to propel itself across the seafloor with bands of minute, hydraulically powered tube feet.

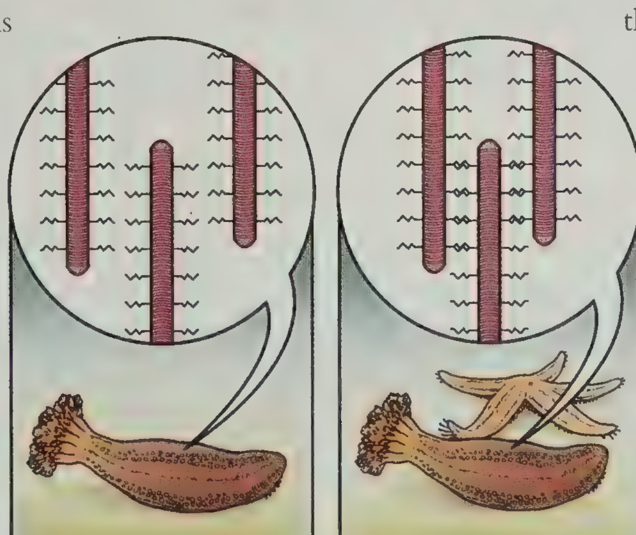
Catch connective tissue, also called mutable connective tissue, is a dense, white, fibrous material that makes up the dermis, or body wall, of the sea cucumber. What grabs the biomechanist's interest is that it can change from stiff to flexible and back again with ease. For example, when you hold the sea cucumber's skin between your thumb and forefinger, at first it feels soft. Within moments, though, it hardens, retaining the indentations of your hand for some time. Catch connective tissue enables the foraging sea cucumber to be soft enough to flow into nooks and crannies in pursuit of food. But it could also enable the creature to "don" leathery armor rapidly when a predator threatens (though that possiblity has not been tested).

A mammal's tendon can do no such trick. But both mammalian and catch connective tissue do share common structures. Both are made up of collagen fibrils, and the fibrils of both are suspended in a gooey material that makes the tissues "viscoelastic." (The goo, called the extracellular matrix, is made of water, proteins, and compounds known as proteoglycans, with filaments known as microfibrils suspended in it to serve as scaffolding.) A viscoelastic material acts partly like a solid and partly like a fluid. Under a rapidly applied load, the material reacts like a solid, deforming slightly but holding its shape, and pushing back as hard as it is pushed on. Under a force applied for a sustained period of time, the material reacts like a liquid, slowly taking whatever shape its surroundings impose. Silly Putty is a good example. A ball of the stuff bounces like a Super Ball when thrown, but it flows so well under steady, slow pressure that it takes a nice fingerprint.

The great trick of catch connective tissue, however, isn't just that it has both viscous (fluid) and elastic (solid) properties; it's that the tissue's viscoelasticity can change. Some cells in the dermis secrete a plasticizing protein that loosens the grip on the collagen fibrils, enabling them to slide past one another and making the overall tissue soft and pliable. Other cells release a stiffening factor that causes the fibrils to "catch" and make the dermis far stiffer.

Biomechanists Greg K. Szulgit of Hiram College in Ohio and Robert E. Shadwick of the Scripps Institution of Oceanography in La Jolla, California, were able to extract chemical derivatives of both the "stiffeners" and the "plasticizers" from the dermis cells. Those derivatives gave the investigators a tool for altering the material properties of pieces of dermis at will, and thus to address a key question about the mechanism for the mutable viscoelasticity: Does the mutability originate from changes in the solid collagen fibrils, or from changes in the viscous, gooey matrix in which they are suspended (or both)?

Szulgit and Shadwick posited three different mechanisms for the mutable viscoelasticity: First, the linkages between the collagen fibrils might unfasten in the presence of the plasticizer, allowing the fibrils to move independently of each other and thus making the dermis flexible. Second, the fibrils might become more tightly bound to the gooey fluid. Or, third, the goo might become more viscous.



Echinoderms, the phylum that includes sea stars, sea urchins, and sea cucumbers, possess a kind of connective tissue that, unlike human ligaments and tendons, has variable viscoelastic properties. The material, known as catch (or mutable) connective tissue, has two states—pliable and stiff—that are mediated by two proteins. Recent research suggests that in the pliable state, collagen fibrils that make up the catch connective tissue are unattached to each other (left panel of schematic diagram). Something, perhaps a threat from a predator, causes bonds to form between the fibrils (right panel), stiffening the tissue and making it resist physical deformation.

To distinguish among the three possibilities Szulgit and Shadwick set slabs of sea cucumber dermis on a fixed bottom and rapidly oscillated the top surface of each slab. They measured the force it took to move the top relative to the bottom when the tissue was stiff, and again when it was relaxed. The two investigators confirmed early work indicating that cellular extracts can change the stiffness of dermis between tenfold and seventyfold. Furthermore, the way the movements of the top and bottom of the dermis responded to the applied force shed light on the nature of the stiffened tissue. As the stiffness of the dermis samples increased, the contribution of the viscous matrix to the stiffness decreased.

The most likely explanation for those results is that the stiffener causes bonds to form between pairs of collagen fibrils or between collagen and other solid elements in the matrix. The plasticizer probably works by breaking those same bonds. That mechanism, though better understood, is still a ways from becoming the basis of a practical alternative to the crude splicing of tendons performed by surgeons today. For one thing, the plasticizers and stiffeners have not been well characterized; their exact composition is still a mystery. Nevertheless, I have high hopes that someday soon a surgeon somewhere will repair a career-ending ligament injury with the help of a sea cuke.

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The Lizard Kings

Small monitors roam to the east of an unseen frontier; mammals roam to the west

By Samuel S. Sweet and Eric R. Pianka

A small lizard, caught in the open, flushes ahead of a pursuing monitor. The prey, desperately seeking escape, begins to run a winding course. The tactic could throw a predator off, but the monitor doesn't bite. Rather than engage in a tail chase, the monitor heads straight for a pile of rocks—the only nearby feature to which the hunted animal could possibly escape. The smaller lizard, outsmarted, arrives at the refuge too late.

Such a display of intelligence in monitor lizards, the animals of the family Varanidae, is not unusual. As a rule, monitors do not have to chase their prey very far, and in many cases they seem to anticipate some gambit by their prey. When arboreal lizards are being hunted and run for a tree, they usually spiral around to the back side to ascend; one of us (Sweet) has watched pursuing monitors of two species *(Varanus tristis* and *V. glauerti),* on at least three occasions, spiral around the tree in the opposite direction to catch the prey unawares. (Experienced human lizard-catchers do the same thing.)

The black-palmed rock monitor *(V. glebopalma),* a three-foot-long lizard from northern Australia, hunts by taking up perches on three- to six-foot-high boulders along the margins of ledges, where it has a good view of some area of more-or-less open ground. If it spots prey—such as, in Sweet's observations, a skink or a frog—it literally projects itself off the boulder, dashes after the prey, and then returns with its quarry at top speed to some rock crevice before doing anything like chomping or whacking the prey and gulping it down. "Lizards" don't do this: if they have something in their mouth, they eat it then and there—no matter that something else may be zooming in at top speed in hopes of a double lunch. But monitors do.

Predators and their prey are locked into a co-evolutionary arms race, in which any advantage gained by one calls for a countermeasure by the other. Less sophisticated, or perhaps just unlucky, prey individuals perish. On average, those with better means of escape survive. More effective escape, in turn, favors predators better able to capture evasive prey, and the bar for both species rises in a reciprocating fashion. Similarly, competing lineages of predators—cats and foxes, for example—are also subject to the Red Queen's dictum that "it takes all the running you can do, to keep in the same place."

A common result of such pressures—less adept animals either don't catch a meal or can't avoid being eaten—is the evolution of larger brains and more sophisticated nervous systems, as well as a potential for increased intelligence. A successful carnivore might have better neuromuscular coordination than its peers or its prey; more refined senses (and brain to process the information); or enhanced problem-solving capabilities. Those aspects of neurophysiology co-evolve in turn with ecological and behavioral differences among various kinds of carnivores. The range of possibilities for a predator's behavior—whether it hunts alone or in a pack; whether it lies in wait to ambush or actively chases down its prey; and the degree to which it relies on visual, auditory, or olfactory input to find its meal—all affect the nature and sophistication of the animal's brain.

None of the logic of this arms race leads to the conclusion that effective brains and neural sophistication are restricted to mammals; monitor lizards make that much clear. Superb predators, these animals surpass all other lizards in intelligence. They are alert and agile. Their styles of hunting rely on acute vision and extremely sensitive chemoreception to cover what are typically huge areas relative

Mertens' water monitor (Varanus mertensi) hunts aquatic life in waterways across north central Australia.

to their size. In these and other ways, convergent evolution has led to many similarities between monitors and mammals. Herpetologists have relied on terms such as "mammal-like" and "near-mammalian" so often to describe the monitors that such phrases have nearly become clichés.

The descriptions, however, divert attention from a question that is far more intriguing than mere similarities in habits between the two groups of vertebrates: Are the two groups so similar that they are ecologically incompatible as top carnivores? In other words, does the presence of one group in an ecosystem restrict the presence of the other? An analysis of the capabilities of monitor lizards and small mammalian carnivores, combined with the study of their biogeography, may throw some light on whether, in some ecosystems, the monitor lizards became a fair match for the mammals.

The similar adaptations of monitor lizards and mammalian carnivores are certainly not the products of a shared family history. The most recent common ancestor of the two groups lived more than 300 million years ago. It was a far less sophisticated animal, lacking the metabolic scope, visual and chemoreceptive abilities, and complex information processing that characterize both groups today. Most contemporary features of monitors and mammals that function in similar ways are clearly not the results of similar anatomical endowments.

One substantial difference is that monitors are ectotherms—loosely referred to as being cold-blooded. The more familiar term is something of a misnomer, because the "cold-blooded" monitors, at least, typically operate at tightly regulated body temperatures equal to or higher than those of mammals. Monitors, however, do without the

costly molecular and physiological control mechanisms required by endotherms, the so-called warm-blooded animals. Both monitors and mammals can sustain their activities for long periods.

Monitors do not sense chemicals with the nasal olfactory chamber that is so well developed in mammals. Instead, they transfer compounds from their tongues into two elaborate sensory receptors known as the vomeronasal organs. Vestigial in mammals, these organs occupy paired cavities that open onto the roof of the monitor's mouth.

Many accounts of monitors in captivity cite behaviors unusual among reptiles that attest to sophisticated information-processing capabilities. White-throated monitors *(V. albigularis)* can count up to six. Komodo dragons *(V. komodoensis)* recognize their keepers. When chasing rats, crocodile monitors *(V. salvadorii)* anticipate evasive tactics. Few field studies, however, have explored the monitor intellect, and the wariness of monitors in the wild is legendary. But the work that has been done demonstrates that the animals can locate terrain features, mates, and food both by memory and with their remarkably sensitive chemical detectors.

Monitors are renowned trackers. Alexey Y. Tsellarius of the Severtsov Institute of Ecology and Evolution in Moscow and his colleagues found that Caspian monitors *(V. griseus caspius)* can distinguish male from female and resident from nonresident monitors merely by sampling their tracks with the vomeronasal organ. If the monitor then gives chase, it unhesitatingly follows the track of the other animal in the correct direction. Our observations in Australia corroborate Tsellarius's finding for both desert and woodland species. One of us (Pianka) once came upon the track of a large monitor known as a perentie *(V. giganteus)* that had intercepted his own. The track showed that the lizard "ricocheted" off the human footprints and fled in the direction it came from, illustrating its chemosensory talents.

Monitors that feed on the eggs of other reptiles can locate a clutch buried in sloping, backfilled tunnels. They do not gain access via the tunnel entrance, which is often three feet or more away from the eggs; instead, they dig straight down from above. Walter Auffenberg, a herpetologist formerly at the Florida Museum of Natural History in Gainesville, demonstrated that Komodo monitors can detect carrion from nearly seven miles away. Auffenberg also concluded that some monitors climb to ridgelines expressly to sniff the wind for carrion odors over a large area, a foraging strategy that requires substantial planning.

Monitors can apparently recall the positions of refuges within their home ranges. Pianka has observed that such Australian desert species as the perentie and the rusty desert monitor *(V. eremius)* remember exactly where good burrows are located: the lizards head directly toward them cross-country, which for perenties may be a mile or more. Lace monitors *(V. varius)* display a similar talent, though put to different use: They lay their eggs in active termite mounds, then return about nine months later to reopen the nests for the hatchlings to exit. Such a feat calls for map knowledge as well as an accurate sense of timing.

With the tongue monitor lizards sample the air for chemical compounds, then transfer the compounds into two cavities that open into the roof of the mouth. The cavities house elaborate chemical sensors called the vomeronasal organs. Pictured here is the common water monitor (V. salvator).

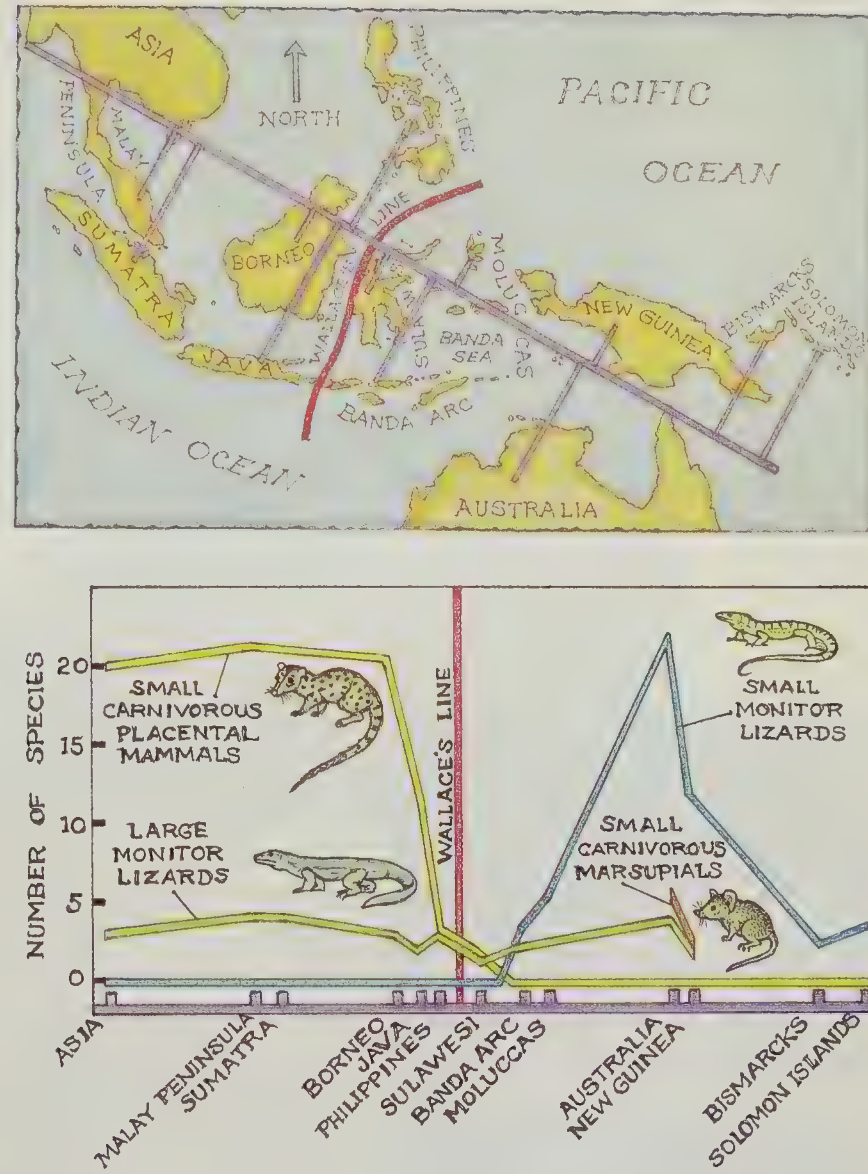
Radiotransmitters attached to individual monitors make it possible to follow them closely. We have learned, for instance, that male monitors seek out multiple partners by visiting the home ranges of several females. Sweet observed a male of the small arboreal species *V. glauerti* descend the

home tree of one female and travel more than 300 yards in a straight line, through dense forest and rock outcrops, to the base of another tree. Six days earlier, he had mated with a second female in that tree, but in the interim she had relocated twice. So, finding no one home, the male trailed her to a third tree fifty yards away, then traveled another seventy-six yards to a fourth tree, where the second female then resided. The entire episode took only forty-five minutes and covered nearly 440 yards in rugged terrain.

This feat called on both mental maps and expert chemical detection. The male was familiar enough with his eighteen-acre home range to make a straight-line return to the second female's old location. Then he tracked her by her odor trail. Each of five male *V. glauerti* studied displayed similar abilities. And Pianka in Australia observed a male of the small arboreal black-tailed monitor *V. tristis* travel 790 yards in a straight line into the wind in one day; it was found in a hollow tree with a female, suggesting that it may have followed an airborne scent trail to find her.

Monitors sometimes adopt unusual foraging tactics. Some semiaquatic species, such as Mertens' water monitor *(V. mertensi)*, use their body and tail to herd fishes into shallow water. The black-tailed monitor has a unique tactic to rustle up skinks, the small lizards on which it feeds. Sweet watched several black-tailed monitors hunting skinks in leaf-filled depressions. The monitors would surge forward under the dry litter and then pop up, holding the head high and ready to pounce on any movement. After a few moments of watching, some individuals abruptly began to twitch and wiggle their tails under the leaves. The twitching sometimes caused a concealed skink to reveal its location.

Many people are familiar with the differences between cats and dogs, as well as between individuals of either group. Similar patterns show up in monitors, both in species and in individuals. During field studies that brought Sweet into daily contact with individuals of several species, he found that some male members of some species became habituated to his presence. Those lizards could be followed closely, and some even climbed onto him a few times. Others, however, became less approachable as his studies continued. Four out of six *V. glauerti*, two out of forty-two *V. scalaris*, and three out of twelve *V. tristis* habituated, whereas each of twelve *V. glebopalma* and five each of *V. scalaris* and *V. tristis* became increasingly wary with time. Either way, the animals clearly recognized and remembered him. Curiously, however, no females of any of these species ever habituated.



Transect line (purple line on map and on horizontal axis of graph) reveals a complementary distribution of species of carnivorous mammals and small monitor lizards. The transect, defined by the authors, makes a roughly perpendicular intersection with a biogeographic barrier first described by Alfred Russel Wallace. Wallace's Line marks the eastern limit of many animals having Southeast Asian affinities, and the western limit of a fauna derived from Australia and New Guinea. On the graph below the map, the number of species belonging to four groups of animals is plotted for various ecosystems that occur along the transect. The graph shows that the diversity of small carnivorous mammals (yellow) and that of small monitors (blue) are virtually mirror images of each other, as if they were reflected across Wallace's Line. The diversity of large monitor species (green) fluctuates randomly across the transect line. The pattern suggests that carnivorous mammals and small monitors may be too similar as predators to coexist, or that the small monitors become prey for the mammals when both are introduced into the same ecosystem. Interestingly, carnivorous marsupials (orange) do not prey on monitors, suggesting that the monitors can outsmart the marsupials but are outdone by the mammals.

None of the complex behaviors we are describing commonly occurs in other reptiles. And certainly no reptiles except monitors have such a broad repertoire of "mammal-like" attributes.

Throughout Africa and southern Asia monitors coexist successfully with a wide range of carnivorous mammals. The diversity of monitor species on those continents, however, is fairly low, and most of them are large (meaning the adults are more than four feet long) and relatively bulky. Six species occur in Africa and the Arabian peninsula, and one of those extends well into central Asia. Six more species range across mainland southern Asia.

As one moves east, into offshore Southeast Asia, the diversity of monitors increases sharply. Fourteen species are native to the East Indies and the Philippines (four of them also live on the mainland), and sixteen species are native to New Guinea, the Solomon Islands, and the islands of the Bismarck Archipelago.

That high diversity of small monitors in eastern Indonesia and Melanesia has only recently been recognized. Before 1990 only three small species were known in the region: the widespread mangrove monitor *(V. indicus)*, which varied greatly from island to island; the green tree monitor *(V. prasinus)* of New Guinea; and *V. timorensis*, of Timor. Through the efforts of Wolfgang Boehme, a zoologist at the Alexander Koenig Research Institute in Bonn, Germany, and his colleagues, sixteen additional species are now recognized. That work alone has increased the species count of the family Varanidae by about 25 percent. Some of the newly recognized species are local derivatives of the widely ranging *V. indicus* and *V. prasinus;* others are more distinct.

Northern quoll (Dasyurus hallucatus; *top), a carnivorous marsupial native to Australia, and the masked palm civet* (Paguma larvata; *above), a carnivorous mammal native to Southeast Asia, both coexist with large monitor lizards. Species of small monitors, however, thrive only where the civet and its kin are absent.*

The diversity of monitors reaches its peak in Australia, which hosts twenty-seven named species (five are shared with New Guinea) and more than a dozen as yet undescribed species as well. In parts of northern Australia as many as eight or nine species may occur in the same areas, partitioning resources according to differences in body size and habit. One unique and important feature of the Australasian radiation of monitor species is that more than half of them are small (adults less than four feet long) and of slender build.

To understand why small monitor species have radiated so dramatically through Australia, New Guinea, and their adjacent islands, but not elsewhere, we examined the possible role of Wallace's Line [*see map on preceding page*]. Alfred Russel Wallace, the nineteenth-century naturalist, did extensive fieldwork in what is now Indonesia, where he noted a sharp dichotomy in fauna between certain islands. One side of the line he traced to mark the dichotomy represents the eastern limit of many animals with Southeast Asian affinities; the other side is the western limit of a fauna derived from Australia and New Guinea.

Wallace's Line is now understood to overlie a region incorporating three major tectonic plates and several smaller ones. Thousands of islands made up of transient volcanic peaks and scattered microcontinental fragments are sandwiched between the eastern edge of the Asian continental shelf and the shelf that encloses Australia and New Guinea. Most important to the biota, no land connections have ever spanned Wallace's Line, and so it represents an absolute limit to the dispersal of organisms that cannot cross the sea. For other species, the line is just a filter, and it is almost irrelevant for many plants or insects that can fly long distances.

The lands in the vicinity of Wallace's Line provide a natural laboratory for testing ideas about the ecological equivalence of mammals and monitors. Virtually none of the small carnivorous mammals of Southeast Asia (cats, civets, mongooses, weasels) have crossed it from west to east on their own. Just one species of civet is native to Sulawesi, to the east of Wallace's Line; other civet and mongoose species in the archipelago were introduced by people.

In contrast to its influence on the mammals, Wallace's Line is not a barrier to monitors—or is it? That depends on the adult size of the species [*see lower illustration on preceding page*]. Large monitor species (in which adults are greater than four feet long) are just as diverse on lands east of Wallace's Line as they are to the west, or for that matter in mainland Asia and Africa. Small monitor species, however, occur only to the east of the line. Their diversity in that region forms a near-mirror image of the species distribution of small carnivorous mammals to the west. And Sulawesi, the only island east of Wallace's Line that harbors a native placental mammalian carnivore, lacks small monitors.

Did the small monitors, like the small carnivorous mammals, simply halt their radiation at Wal-

*Member of the mangrove monitor group (*V. indicus *and other species) is pictured in New Guinea. The group's domain extends from the islands around the Banda Sea to the Solomon Islands. The* indicus *group radiated into a variety of habitats; the absence of small placental carnivores has probably facilitated that spread.*

lace's Line? Probably not: most monitors are accomplished rafters, and so their distributions probably did not arise from any geographical barrier. Instead, the distributions may have an ecological explanation: the two groups are simply too similar as predators to coexist, and on the landmasses west of Wallace's Line, the small mammals prevailed.

One informative twist on this idea arises in Australia and New Guinea. Many small carnivorous marsupials live there, and some of them—six species of quolls and one phascogale—grow to about the size of civets and mongooses [*see photographs on opposite page*]. These marsupial carnivores are fierce and agile predators, yet they have evolved and coexist with many species of small monitors.

The behavior of these groups and the ways their ecologies overlap suggest that small monitors are, roughly speaking, "dumber than civets but smarter than quolls." Unfortunately, that simple generalization is being tested by human interventions. Mongooses and civets have been introduced to islands east of Wallace's Line, and foxes and feral cats have been brought to Australia. In a recent field study in northern Australia, Sweet lost thirteen out of fifty-four individual monitors to predation: four were killed by native predators, but nine were taken by a single feral cat. The northern quoll *(Dasyurus hallucatus),* however, failed to catch any of the monitors.

To complete our story, we must point out that small monitors actually do coexist with small placental mammalian carnivores such as civets and mongooses—in the form of juveniles of the large monitor species! The young of these large monitors are typically highly secretive and often arboreal, but so are many of the small monitor species. Thus, secrecy is not a sufficient explanation for coexistence. We suggest that this coexistence succeeds because large adults can lay many eggs and the young grow quickly; even if many become prey to carnivores, a few will probably reach adult size. Species of small monitors lay fewer eggs, and must spend their entire lives in the arms race with small mammals. Whether they lose out primarily because they become prey, or because they must compete for prey with mammals, remains to be studied.

Wherever monitors live, the arms race has honed their original predatory tool kit. Particularly to the east of Wallace's Line, monitors appear to have achieved striking ecological and behavioral parity with mammals. A century ago the German herpetologist Franz Werner proclaimed monitors "the proudest, best-proportioned, mightiest, and most intelligent of all lizards." We certainly concur, and could add many superlatives to Werner's list. Human beings are fortunate to share this planet with such extraordinary animals, and we should try to learn from them whatever we can. □

Trashed

Across the Pacific Ocean, plastics, plastics, everywhere

By Charles Moore

It was on our way home, after finishing the Los Angeles-to-Hawaii sail race known as the Transpac, that my crew and I first caught sight of the trash, floating in one of the most remote regions of all the oceans. I had entered my cutter-rigged research vessel, *Alguita,* an aluminum-hulled catamaran, in the race to test a new mast. Although *Alguita* was built for research trawling, she was also a smart sailor, and she fit into the "cruising class" of boats that regularly enter the race. We did well, hitting a top speed of twenty knots under sail and winning a trophy for finishing in third place.

Throughout the race our strategy, like that of every other boat in the race, had been mainly to avoid the North Pacific subtropical gyre—the great high-pressure system in the central Pacific Ocean that, most of the time, is centered just north of the racecourse and halfway between Hawaii and the mainland. But after our success with the race we were feeling mellow and unhurried, and our vessel was equipped with auxiliary twin diesels and carried an extra supply of fuel. So on the way back to our home port in Long Beach, California, we decided to take a shortcut through the gyre, which few seafarers ever cross. Fishermen shun it because its waters lack the nutrients to support an abundant catch. Sailors dodge it because it lacks the wind to propel their sailboats.

Laysan albatross is a species that forages throughout the North Pacific [illegible] regurgitated stomach contents, or boluses, of many such bi[illegible] contain plastic debris.

I often struggle to find words that will communicate the vastness of the Pacific Ocean to people who have never been to sea. Day after day, *Alguita* was the only vehicle on a highway without landmarks, stretching from horizon to horizon. Yet as I gazed from the deck at the surface of what ought to have been a pristine ocean, I was confronted, as far as the eye could see, with the sight of plastic.

It seemed unbelievable, but I never found a clear spot. In the week it took to cross the subtropical high, no matter what time of day I looked, plastic debris was floating everywhere: bottles, bottle caps, wrappers, fragments. Months later, after I discussed what I had seen with the oceanographer Curtis Ebbesmeyer, perhaps the world's leading expert on flotsam, he began referring to the area as the "eastern garbage patch." But "patch" doesn't begin to convey the reality. Ebbesmeyer has estimated that the area, nearly covered with floating plastic debris, is roughly the size of Texas.

My interest in marine debris did not begin with my crossing of the North Pacific subtropical gyre. Voyaging in the Pacific has been part of my life since earliest childhood. In fifty-odd years as a deckhand, stock tender, able seaman, and now captain, I became increasingly alarmed by the growth in plastic debris I was seeing. But the floating plastics in the gyre galvanized my interest.

I did a quick calculation, estimating the debris at half a pound for every hundred square meters of sea surface. Multiplied by the circular area defined by

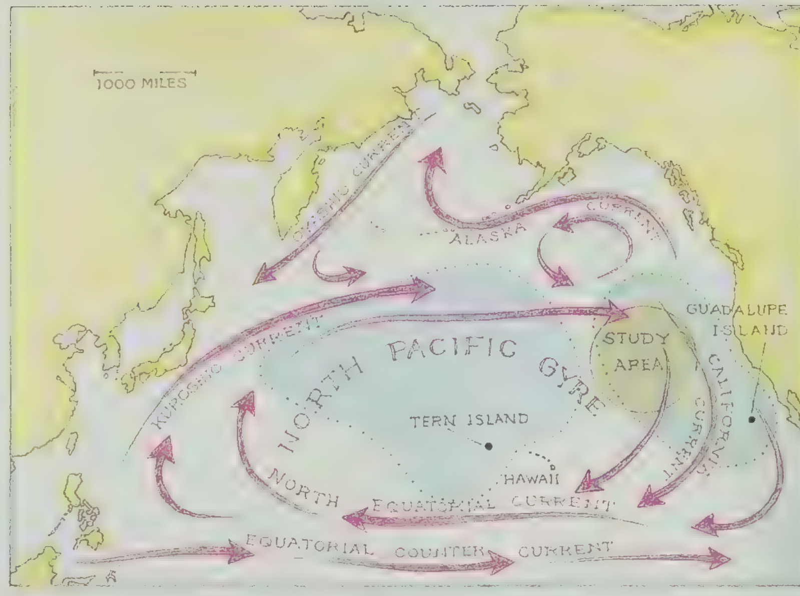
Bottle caps and other plastic objects are visible inside the decomposed carcass of this Laysan albatross on Kure Atoll, which lies in a remote and virtually uninhabited region of the North Pacific. The bird probably mistook the plastics for food and ingested them while foraging for prey.

our roughly thousand-mile course through the gyre, the weight of the debris was about 3 million tons, comparable to a year's deposition at Puente Hills, Los Angeles's largest landfill. I resolved to return someday to test my alarming estimate.

Historically, the kind of drastic accumulation I encountered is a brand-new kind of despoilment. Trash has always been tossed into the seas, but it has been broken down in a fairly short time into carbon dioxide and water by marine microorganisms. Now, however, in the quest for lightweight but durable means of storing goods, we have created a class of products—plastics—that defeat even the most creative and voracious bacteria.

Unlike many discarded materials, most plastics in common use do not biodegrade. Instead they "photodegrade," a process whereby sunlight breaks them into progressively smaller pieces, all of which are still plastic polymers. In fact, the degradation eventually yields individual molecules of plastic, but these are still too tough for most anything—even such indiscriminate consumers as bacteria—to digest. And for the past fifty years or so, plastics that have made their way into the Pacific Ocean have been fragmenting and accumulating as a kind of swirling sewer in the North Pacific subtropical gyre.

It surprised me that the debris problem in the gyre had not already been looked at more closely by the scientific community. In fact, only recently—starting in the early 1990s—has the scientific community begun to focus attention on the trash in the gyre. One of the first investigators to study the problem was W. James Ingraham Jr., an oceanographer at the National Oceanic and Atmospheric Administration (NOAA) in Seattle. Ingraham's Ocean Surface Current Simulator (OSCURS) predicts that



Currents in the North Pacific move in a clockwise spiral, or gyre, which tends to trap debris originating from sources along the North Pacific rim. Plastics and other waste have accumulated in the region, which includes the foraging areas of Pacific bird colonies, such as that of the Tern Island albatross, shown in blue, and that of the Guadalupe Island albatross, shown in green.

objects reaching this area might revolve around in it for sixteen years or more [*see illustrations on opposite page*].

A year after my sobering voyage, I asked Steven B. Weisberg, director of the Southern California Coastal Water Research Project and an expert in marine environmental monitoring, to help me make a more rigorous estimate of the extent of the debris in the subtropical gyre. Weisberg's group had already published an article on the debris they had collected in fish trawls of the Southern California Bight, a region along the Pacific coast extending a hundred miles both north and south of Los Angeles. As I discussed the design plan for our survey with Weisberg's statisticians, Molly K. Leecaster and Shelly L. Moore, it became apparent that we were facing a new problem. In the coastal ocean, bodies of water are naturally defined, in part, by the coasts they lie against. In the open ocean, however, bodies of water are bounded by atmospheric pressure systems and the currents those systems create. In other words, air, not land, defines the body of water. Because air pressure systems move, the body of water we wanted to survey would be moving as well. A random sample of a moving area such as the gyre would have to be done quite differently from the way Weisberg's group had conducted their survey along the Pacific coast.

The gyre we planned to survey is one of the largest ocean realms on Earth, and one of five major subtropical gyres on the planet. Each subtropical gyre is created by mountainous flows of air moving from the tropics toward the polar regions. The air in the North Pacific subtropical gyre is heated at the equator and rises high into the atmosphere because of its buoyancy in cooler, surrounding air masses. The rotation of the Earth on its axis moves the heated air mass westward as it rises, then eastward once it cools and descends at around 30 degrees north latitude, creating a huge, clockwise-rotating mass of air [*see map on this page*].

The rotating air mass creates a high-pressure system throughout the region. Those high pressures depress the ocean surface, and the rotating air mass also drives a slow but oceanic-scale surface current that moves with the air in a clockwise spiral. Winds near the center of the high are light or even calm, and so they do not mix the floating debris into the water column. This huge region, what I call a "gentle maelstrom," has become an accumulator of debris from innumerable sources along the North Pacific rim, as well as from ships at sea.

Filter-feeding chordate jellyfishes known as "salps" dominate the North Pacific subtropical gyre. Investigators aboard the research vessel Alguita observed salps in the gyre, such as the one shown here, with brightly colored plastic fragments in their bellies.

The subtropical gyres are also oceanic deserts—in fact, many of the world's land-based deserts lie at nearly the same latitudes as the oceanic gyres. Like their terrestrial counterparts, the oceanic deserts are low in biomass. On land the low biomass is caused by the lack of moisture; in oceanic deserts the low biomass is a consequence of great ocean depths.

In coastal areas and shallow seas, winds and waves constantly stir up and recycle nutrients, increasing the biomass of the food web. In the deep oceans, though, such forces have no effect; the bottom sequesters the nutrient-rich residue of millions of years of near-surface photosynthetic production, as well as the decomposed fragments of life in the sea, trapping them miles below the surface. Hence the major

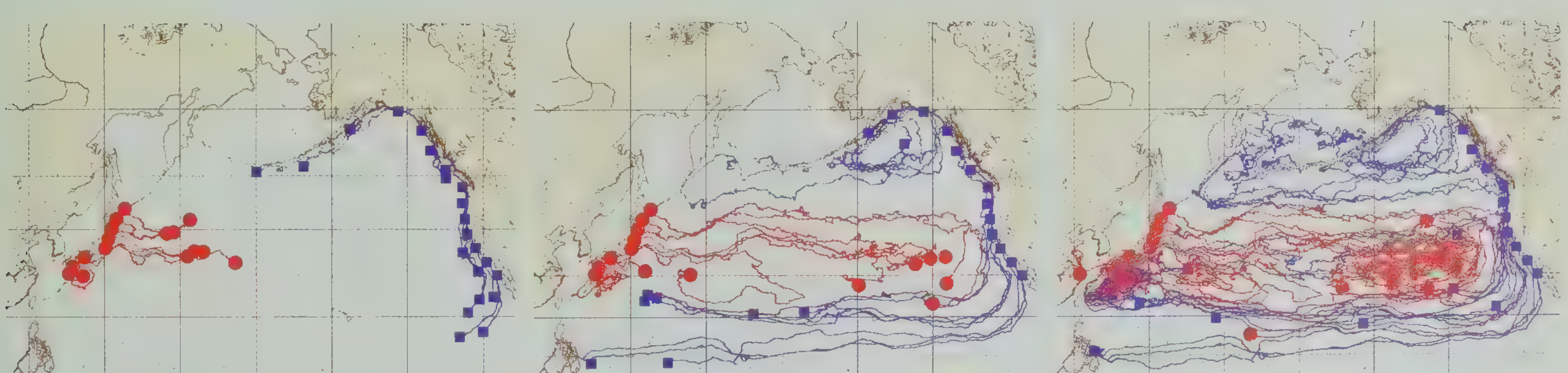
source of food for the web of life in deep ocean areas is photosynthesis.

But even in the clear waters that prevail in the subtropical gyres, photosynthesis is confined to the top of the water column. Sunlight attenuates rapidly with depth, and by the time it has gone only about 5 percent of the way to the bottom, the light is too weak to fuel marine plants. The net effect is a vast area poor in resources, an effect that makes itself felt throughout the food web. Top predators such as tuna and other commercially viable fish don't hang out in the gyres because the density of prey is so low. The human predator stays away too: the resources that have drawn entrepreneurs and scientists alike to various regions of the ocean are not present in the subtropical gyres.

What does exist in the gyres is a great variety of filter-feeding organisms that prey on the ever-renewed crop of tiny plants, or phytoplankton. Each day the phytoplankton grow in the sunlit part of the water, and each night they are consumed by the filter feeders, a fantastic array of alien-looking animals called zooplankton. The zooplankton include chordate jellyfishes known as "salps," which are among the fastest-growing multicellular organisms on the planet. By fashioning their bodies into pulsating tubes, the salps are able, each day, to filter half the water column they inhabit, drawing out the phytoplankton and smaller zooplankton for food. But salps are gelatinous creatures with a low biomass, and so there is no market for them, either. Hence the realm they dominate, one of the largest uniform habitats on the planet, remains unexploited and largely unexplored.

Leecaster, Moore, and I came up with a plan to make a series of trawls with a surface plankton net, along paths within a circle with a 564-mile radius. The area of the circle would then be almost exactly 1 million square miles. Trawling would start when we estimated we were under the central pressure cell of the high-pressure system that creates the gyre. We would regard the starting point as the easternmost point along the circumference of the circle. Then we would proceed due west to the center of the circle, turn south, and sail back to the southernmost point on the circumference, alternating between trawling and cruising. We intended to obtain transect samples with random lengths and random spacing between trawls. To be conservative about our sampling technique, we decided that any debris we collected would count only as a sample of the debris within the area of the transected circle.

In August 1998 I set out with a four-member volunteer crew from Point Conception, California heading northwest toward the subtropical gyre. Onboard *Alguita* was a manta trawl, an apparatus resembling a manta ray with wings and a broad mouth, which skimmed the ocean surface trailing a net with a fine mesh. Eight days out of port, the wind dropped below ten knots and we decided to practice our manta trawling technique, taking a sample at the edge of the subtropical gyre, about 800 miles offshore. We pulled in the manta after trawling three and a half miles.



Ocean Surface Current Simulator (OSCURS) model developed by W. James Ingraham Jr., an oceanographer at the National Oceanic and Atmospheric Administration (NOAA), predicts the trajectory of drift originating along the coasts of the North Pacific rim. Drift from Japan is shown in red; drift from the United States, in blue. The diagrams show the position of drift after 183 days (left), three years (center), and ten years (right).

What we saw amazed us. We were looking at a rich broth of minute sea creatures mixed with hundreds of colored plastic fragments—a plastic-plankton soup. The easy pickings energized all of us, and soon we began sampling in earnest. Because plankton move up and down in the water column each day, we needed to trawl nonstop, day and night, to get representative samples. When we encountered the light winds typical of the subtropical gyre, we deployed the manta outside the port wake, along with two other kinds of nets. Each net caught

plenty of debris, but far and away the most productive trawl was the manta.

There was plenty of larger debris in our path as well, which the crew members retrieved with an inflatable dingy. In the end, we took about a ton of this debris on board. The items included

- a drum of hazardous chemicals;
- an inflated volleyball, half covered in gooseneck barnacles;
- a plastic coat hanger with a swivel hook;
- a cathode-ray tube for a nineteen-inch TV;
- an inflated truck tire mounted on a steel rim;
- numerous plastic, and some glass, fishing floats;
- a gallon bleach bottle that was so brittle it crumbled in our hands; and
- a menacing medusa of tangled net lines and hawsers that we hung from the A-frame of our catamaran and named Polly P, for the polypropylene lines that made up its bulk.

Bolus coughed up by an albatross on Guadalupe Island, Mexico, includes many plastic fragments. Differences in the condition of debris the birds consume—whether it is whole or fragmented—can be traced to the way trash flows into their respective foraging areas. Debris leaving the West Coast of the United States drifts for six years or more—enough time to photodegrade into fragments—before it reaches the Guadalupe Island birds.

In 2001, in the *Marine Pollution Bulletin*, we published the results of our survey and the analysis we had made of the debris, reporting, among other things, that there are six pounds of plastic floating in the North Pacific subtropical gyre for every pound of naturally occurring zooplankton. Our readers were as shocked as we were when we saw the yield of our first trawl. Since then we have returned to the area twice to continue documenting the phenomenon. During the latest trip, in the summer of 2002, our photographers captured underwater images of jellyfish hopelessly entangled in frayed lines, and transparent filter feeding organisms with colored plastic fragments in their bellies.

Entanglement and indigestion, however, are not the worst problems caused by the ubiquitous plastic pollution. Hideshige Takada, an environmental geochemist at Tokyo University, and his colleagues have discovered that floating plastic fragments accumulate hydrophobic—that is, non-water-soluble—toxic chemicals. Plastic polymers, it turns out, are sponges for DDT, PCBs, and other oily pollutants. The Japanese investigators found that plastic resin pellets concentrate such poisons to levels as high as a million times their concentrations in the water as free-floating substances.

The potential scope of the problem is staggering. Every year some 5.5 quadrillion (5.5×10^{15}) plastic pellets—about 250 billion pounds of them—are produced worldwide for use in the manufacture of plastic products. When those pellets or products degrade, break into fragments, and disperse, the pieces may also become concentrators and transporters of toxic chemicals in the marine environment. Thus an astronomical number of vectors for some of the most toxic pollutants known are being released into an ecosystem dominated by the most efficient natural vacuum cleaners nature ever invented: the jellies and salps living in the ocean. After those organisms ingest the toxins, they are eaten in turn by fish, and so the poisons pass into the food web that leads, in some cases, to human beings. Farmers can grow pesticide-free organic produce, but can nature still produce a pollutant-free organic fish? After what I have seen firsthand in the Pacific, I have my doubts.

Many people have seen photographs of seals trapped in nets or choked by plastic six-pack rings, or sea turtles feeding on plastic shopping bags, but the poster child for the consumption of pelagic plastic debris has to be the Laysan albatross. The plastic gadgets one typically finds in the stomach of the bird—whose range encompasses the remote, virtually uninhabited region around the northwest Hawaiian Islands—could stock the checkout counter at a convenience store. My analysis of the stomach contents of birds from two colonies of Laysan albatrosses that nest and feed in divergent areas of the North Pacific [*see map on page 48*] show differences in the types of plastic they eat. I believe those differences reveal something about the way plastic is transported and breaks down in the ocean.

On Midway Island in the Hawaiian chain, a bolus, or mass of chewed food, coughed up by one bird included many identifiable objects. By contrast, a bird on Guadalupe Island, which lies 150 miles off the coast of Baja California, produced a bolus containing only plastic fragments. The principal natural prey of both bird colonies is squid, but as the ecologist Carl Safina notes in his book

Eye of the Albatross, the birds' foraging style can be described as "better full than fussy." Robert W. Henry III, a biologist at the University of California, Santa Cruz, and his colleagues have tracked both the Hawaiian and the Guadalupe populations of birds and found that the foraging areas of each colony in the Pacific are generally nonoverlapping and wide apart.

One difference between the two areas is apparently the way debris flows into them. In Ingraham's OSCURS model, debris from the coast of Japan reaches the foraging area of the Hawaiian birds within a year. Debris from the West Coast of the United States, however, sticks close to the coast until it bypasses the foraging area of the Guadalupe birds, then heads westward to Asia, not to return for six years or more. The lengthy passage seems to give the plastic debris time to break into fragments.

The subtropical gyres of the world are part of the deep ocean realm, whose ability to absorb, hide, and recycle refuse has long been seen as limitless. That ecologically sound image, however, was born in an era devoid of petroleum-based plastic polymers. Yet the many benefits of modern society's productivity have made nearly all of us hopelessly, and to a large degree rationally, addicted to plastic. Many, if not most, of the products we use daily contain or are contained by plastic. Plastic wraps, packaging, and even clothing defeat air and moisture and so defeat bacterial and oxidative decay. Plastic is ubiquitous precisely because it is so good at preventing nature from robbing us of our hard-earned goods through incessant decay.

But the plastic polymers commonly used in consumer products, even as single molecules of plastic, are indigestible by any known organism. Even those single molecules must be further degraded by sunlight or slow oxidative breakdown before their constituents can be recycled into the building blocks of life. There is no data on how long such recycling takes in the ocean—some ecologists have made estimates of 500 years or more. Even more ominously, no one knows the ultimate consequences of the worldwide dispersion of plastic fragments that can concentrate the toxic chemicals already present in the world's oceans.

Ironically, the debris is re-entering the oceans whence it came; the ancient plankton that once floated on Earth's primordial sea gave rise to the petroleum now being transformed into plastic polymers. That exhumed life, our "civilized plankton," is, in effect, competing with its natural counterparts, as well as with those life-forms that directly or indirectly feed on them.

And the scale of the phenomenon is astounding. I now believe plastic debris to be the most common surface feature of the world's oceans. Because 40 percent of the oceans are classified as subtropical gyres, a fourth of the planet's surface area has become an accumulator of floating plastic debris. What can be done with this new class of products made specifically to defeat natural recycling? How can the dictum "In ecosystems, everything is used" be made to work with plastic? □

Contents of a bolus coughed up by an albatross on Midway Island shows that the Hawaiian bird has consumed many identifiable objects. Debris from Japan reaches the foraging area of the Hawaiian birds within a year and is mostly intact.

Fight of the Bumblebee

Insects, like people, are constantly threatened by disease. Bumblebees' simple but effective immune systems shed light on the evolution of immune defenses and the costs of maintaining them.

By Paul Schmid-Hempel

Humming from flower to flower, a bumblebee worker busily collecting nectar and pollen for its colony is, for many, the epitome of nature's peace and tranquillity. Yet nothing could be further from the truth. Not only is the foraging bumblebee always on the verge of an energy crisis; it is also entangled in a lifelong battle with microscopic enemies that try to capitalize on its efforts.

All complex organisms, people included, face essentially the same predicament. Coping with actual disease, of course, makes prodigious demands on one's energy: taking to bed is often the only possible solution. Yet even as we go about the business of ordinary living—working, crowding together in close quarters, caring for children, shopping at a local market—keeping disease at bay takes a constant toll on the body's resources. Ironically, the insects that carry some of the disease organisms against which people must be most on guard, including malaria, dengue, West Nile virus, and leishmaniasis, are themselves locked in equally desperate battles with similar, if not identical, parasites.

Insects battle some of the same parasites that they transmit to people.

Because of their importance as pollinators of fruit crops and flowers, bees have been a focus in the study of disease and disease resistance in "lower" organisms. The most prevalent disease in bumblebees is caused by the trypanosome *Crithidia bombi*—a mobile protozoan closely related to the microorganism that causes human sleeping sickness. *C. bombi* cells are left behind when an infected bee visits a flower, and those cells can survive for a day or two at the bottom of flower tubes. When the next bee visits the flower, the infectious cells are picked up and carried back to the nest, where a few dozen other workers and a queen are put at risk. The disease often spreads rapidly through the colony and then, via more flower visits, to other colonies in the population. By June almost all bumblebee colonies in a population have become infected by *C. bombi,* though a large fraction of workers within each colony do survive the infection.

Another health hazard of collecting nectar and pollen in flowering meadows is that workers are forced to fly slowly when they maneuver around flower stalks. Slower flying speeds invite attacks by female parasitic flies of the family Conopidae. The conopids inject their eggs into the abdomens of foraging worker bees. There the eggs hatch, and the parasite larvae develop inside each bee, rapidly consuming their host from the inside out. Between ten and twelve days later the worker dies as the parasitic larvae pupate inside its body. The pupas survive the winter—while the bee colony hibernates—and in the spring, as new queens and drone bees are born, they develop into adult flies, ready to attack the next batch of vulnerable workers.

The biology of social insects—ants, bees, termites, and wasps—is fascinating in its own right. But I became intrigued with how such organisms deal with the additional threats posed by disease and parasites. Social insect colonies offer a standing invitation for parasites to thrive. Besides being crowded together in one nest, colony members typically are close relatives of one another and therefore susceptible to similar diseases. An abundance of parasites, such as viruses, bacteria, fungi, nematodes, tapeworms, and the larvae of flies, wasps, and moths, are known to infect bumblebees. Collecting common European bumblebees

Bumblebee worker runs a double risk when collecting nectar from a flower. First, viruses, bacteria, and other disease organisms left behind by infected bees can contaminate the flower parts and thereby spread from bee to bee. Second, hovering in place before landing on the flower exposes the bee to attacks by parasitic flies, which inject their eggs into the abdomen of the bee.

(Bombus terrestris) from summer meadows shows that in some years and locations the larvae of conopid flies parasitize two-thirds or more of the worker bees, leaving them with just a week or so to live. A scene of busy bees may look untroubled, but what is actually charming our senses is an army of the living dead. How do bumblebees survive such an onslaught?

Fortunately, bees and other social insects have their countermeasures. The most potent weapon against parasites in the arsenal of every complex organism is the immune system. The insect immune system has ties to that of the common ancestor of insects and vertebrates, dating back more than 450 million years, and has even older affinities with the defense systems of plants. In a dangerous world, it seems, no organism—not even the smallest or most "primitive"—has been able to go entirely without immune defenses. Yet even immunity has its downside. In our work on bumblebees, my colleagues and I have been able to make quantitative estimates of the costs of sustaining a simple

Social insect populations such as (top to bottom) honeybees, weaver ants, and soldier termites live in ideal conditions for the spread of disease. They share close quarters, making rapid infection possible, and they are often close relatives of one another, making them all susceptible to similar disease strains.

immune system. That work has implications beyond the insect world, however, because the insect immune system is, in many ways, a simplified model of our own. Our observations of bees have made it clear that the benefits of immune protection, like nearly everything else in life, must ultimately be balanced against its costs.

Roughly speaking, insects have two kinds of immune responses, which differ primarily in response time and specificity. The more general branch of the immune system is known as the innate, or constitutive, response. Innate defensive machinery can be directed against an infection immediately, though in a nonspecific way. A main element of that response is the so-called proPO cascade (PO stands for the enzyme phenoloxidase), a rapid sequence of biochemical steps that make a large molecule called melanin. Together with its intermediate products, melanin is toxic to most microorganisms. The cascade of reactions begins when PO is converted to an active form that helps catalyze the further chemical steps that lead to melanin. The proPO cascade—stepped up when an infection is recognized—is characteristic of defense systems that occur in such diverse invertebrate organisms as butterflies, starfish, and water fleas.

The proPO cascade and melanin also play a key role in the second major defensive action of the insect's innate immune response. That response, known as encapsulation, is directed mainly against relatively large parasites that invade an insect's body. At least in most insects, the principal players in the process are the blood cells, more properly called hemolymph cells. (Insect "blood," or hemolymph, unlike our own blood, is not delivered to body cells through vessels by a pump. Instead, it freely laps around all the internal organs, propelled by muscle action.)

During encapsulation, specialized hemolymph cells called hemocytes become attracted to an invader, such as the larva of a conopid fly. As the hemocytes attach to its surface and aggregate, the proPO cascade is activated. The resulting melanin acts as a kind of mortar that cements hemocyte "bricks" in place around the larva. Within a few hours, the invader becomes enclosed in a hardened capsule of melanized cells, which seals it off from the rest of the interior of the host.

In addition to their innate immune system, insects can also mount a so-called induced immune response. In that case, the immune system responds more specifically to certain invaders. For example, within thirty minutes after a fungus has penetrated the larva or adult of a fruit fly (Drosophila melanogaster), the fly's immune system starts producing a peptide, or short protein, called drosomycin. The peptide is inactive against bacteria, but it is highly potent against filamentous fungi. Drosophila also produces peptides such as defensin, in response to infection by gram-positive bacteria, and diptericin, in response to gram-negative ones.

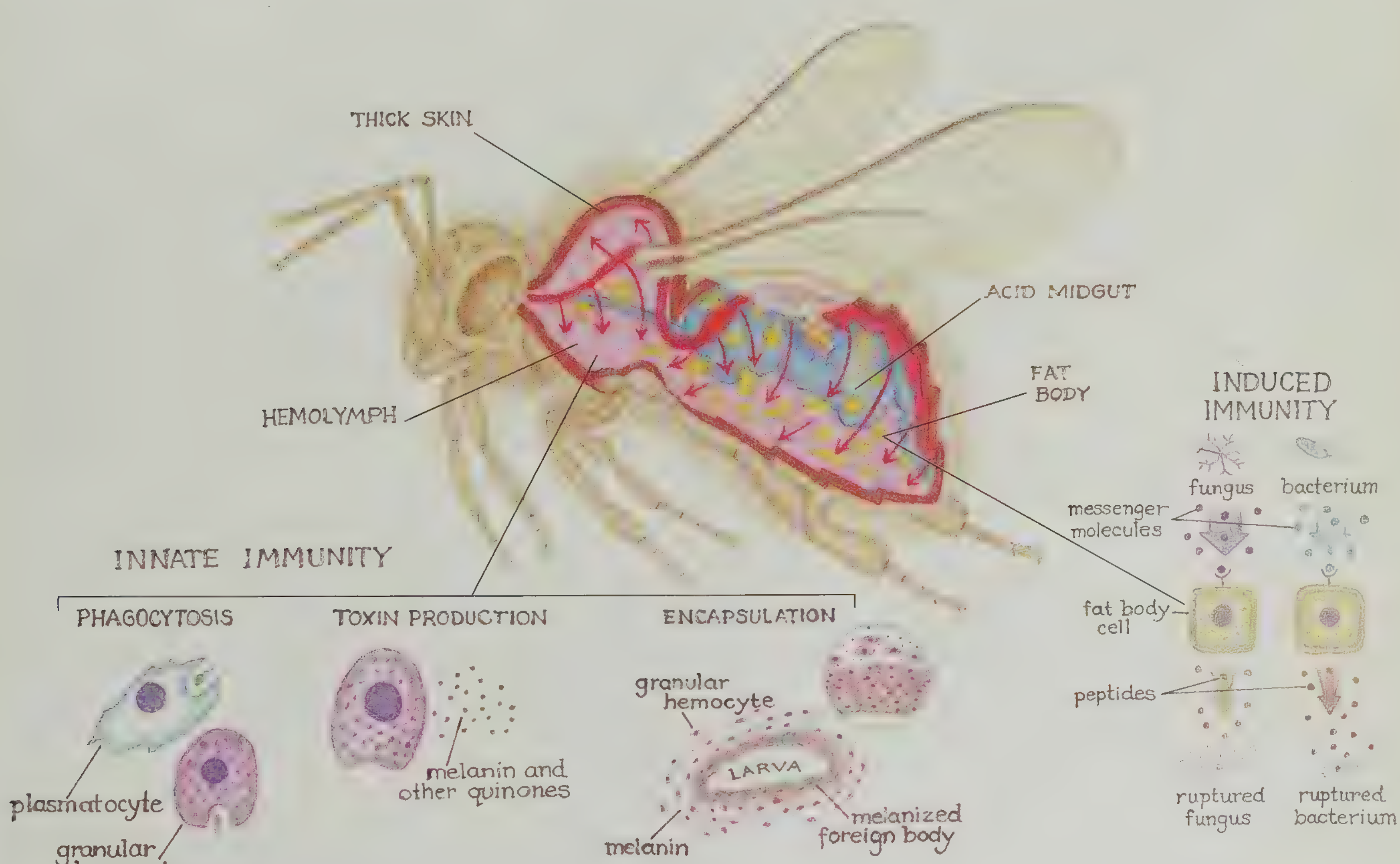
The foreign intruders that trigger distinct induced

immune responses in insects belong to fairly broad categories—bacteria, fungi, and protozoa. At its core, though, the system is a simpler but functional equivalent to the system of induced immunity in mammals. Human immune cells, for example, are exquisitely tuned to produce custom-made antibodies in response to millions of foreign substances, or antigens. The highly specific antibodies and the battalion of destroyer cells of the mammalian induced immune system may seem like the evolutionary pinnacle of precision. Yet, in fact, the simpler insect system requires a smaller overhead to function, and its general effectiveness against the insect's enemies may well render it no less sophisticated than our own.

Whether the immune response is innate or induced, the host must first manage to recognize that a foreign molecule has breached the skin and gotten into its body. In people, a great deal of work has led to a reasonably clear scientific understanding of how the cells of the immune system patrol for foreign substances. Basically, each cell that belongs to the body displays a kind of molecular identity card. Cells acting as sentries patrol for intruders and constantly check the ID cards. Foreign bodies without proper identification are marked for destruction.

Understandably, perhaps, the workings of the insect immune identification system are far less well known. A few of the proteins that act as sentries and recognize intruders have been identified, but most are still obscure. The specificity of the insect system has been deduced simply by observing how it reacts to various experimental infections.

What is clear, nonetheless, is that in both insect and human systems, once an intruder is recognized, a cascade of events is set in motion. Any sentry cell that identifies an intruder spews messenger molecules into the hemolymph (or the blood). Those molecules must then reach various classes of receptors on the surfaces of the cells responsible for the immune reaction. In people, immune cells are concentrated in the bone marrow and the lymph glands. In insects, immune cells occur mostly in the so-



Simplified and stylized diagram of the bee immune system. After getting past the bee's exoskeleton, or "skin," and its acidic midgut, an intruder faces two branches of immune defense: the innate and induced responses. The innate response is a general yet speedy reaction, whereas the slower induced response can tell the difference between, say, fungi or bacteria. (Early steps in the activation of the induced immune response are not well understood.)

called fat body, a decentralized organ that is spread out over almost the entire interior of the insect.

Two main insect immune receptors have been identified to date: the Toll-receptor, which plays a role in the defense against fungi, and a receptor associated with the so-called IMD pathway, which is mostly a mechanism for defense against bacteria. Once activated by the messenger molecules, the insect immune cells produce peptides, which are then secreted into the hemolymph.

Insect peptides have potent antimicrobial properties, and act more or less specifically against the various categories of pathogens: gram-negative bacteria, gram-positive bacteria, and fungi. Not much is known about how the peptides act against bacteria, but one important effect is that they alter the permeability of the bacterial cell membrane. That change eventually kills the invader.

Insects may turn out to be a rich source of powerful antibiotics for people.

Two such peptides in the bee, hymenoptaecin and apidaecin, attack many kinds of bacteria. In fact, their targets include several well-known human pathogens, such as *Enterobacter, Escherichia coli, Salmonella, Shigella, Streptococcus, Staphylococcus,* and *Yersinia.* That raises an exciting possibility for medicine. Insects are by far the most species-rich group of animals on the planet, and the diversity of their antimicrobial peptides must also be enormous. Some of those peptides may well turn out to be powerful antibiotics for our own medical purposes.

The insect immune system mobilizes defenses for coping with the various threats bumblebees may encounter. But effective protection comes at a cost. Everyday life offers plenty of good analogies. A burglar alarm in your house, for instance, is costly to purchase and operate, even if you never use it. Moreover, once it is activated, you have to call in the police for an effective defense.

Insects face similar trade-offs—though the currency in which costs are counted is Darwinian fitness, not dollars. Consider what happens when closely related honeybees, or lines, are selected for resistance to foulbrood, a bacterial disease of honeybee larvae. It turns out that the foulbrood-resistant larvae grow more slowly than the lines susceptible to the disease. Similarly, fruit flies selected to resist the attacks of parasites are less competitive foragers than their nonresistant counterparts. And Indian meal moths selected to resist granulosis virus have fewer offspring than the moths that carry no such immunity. In all those cases the price of having the immunity is paid in the reduced fitness of some other component of the organism.

Immune readiness is not the only aspect of immunity that has a cost; the actual deployment of an immune response is costly, too. Along with my collaborators, I have experimentally investigated that cost in bumblebees. We first tested their innate response by fooling their immune systems into reacting to an artificial parasite. Early in the morning, we implanted a thread of nylon into the body cavities of workers of *B. terrestris.* The nylon was chosen to mimic the larva of a conopid fly.

One group of bees was then allowed to fly out for food, while the other group was kept from leaving the hive. Flying consumes a great deal of energy, and so, we reasoned, the energy demands of flying would compete with the energy needed to fuel the immune response. We retrieved the nylon implant after the bees had worked for a day. Sure enough, the bees that were allowed to fly encapsulated the nylon thread 20 percent less often than the bees that were kept from flying. Such a difference could be just enough for a parasite to survive a bee's immune response, with fatal consequences for the bee.

We also tested the bees for the costs of mounting an induced immune response. In that experiment we again activated the bumblebees' immune systems, but without introducing any stand-in for an actual parasitic infection. Instead, we extracted lipopolysaccharide (LPS) molecules from the surface of gram-negative bacteria and injected a dose of LPS into the worker bees' hemolymph with a fine needle. As we expected, the bees' immune systems recognized the molecules and subsequently released specific antibacterial peptides into the hemolymph—even though no bacterial infection was ever really present. To our surprise, however, we detected no negative consequences. The test bees behaved normally, unimpressed by the energy challenge of having to activate their immune systems. They seemed to carry on with their daily routines.

Only later were we able to tease out the costs of the immune response. Our first group of bees had free access to energy, in the form of sugar water. But in a later test group, we denied the bees sugar water, then carried out the rest of our procedure with LPS. That time, the immune response took its toll. Almost regardless of how their immune systems were challenged, those bees were more than 50 percent more likely to die than their unchallenged counterparts.

Our findings suggest that sometimes the actual damage inflicted by a parasite on its host—whether bumblebee, human, or otherwise—may not even be caused directly by the parasite. Rather, the costs to the host of mounting a defense, even a "successful" one, could lead to damage unless the host can offset those costs, say, by consuming more food. The costs of defense are probably borne by all organisms all the time, just to keep parasites in check. Usually organisms are oblivious to the stress, except when conditions become so unfavorable as to reveal it.

We also discovered that individual bumblebees were not the only entities to pay a price. When we challenged the workers of a colony with small injections of LPS over the life cycle of the entire colony, a major loss in reproductive capacity ensued. Even though no worker ever got sick (since no actual parasite is involved), the colony still lost at least half its normal numbers of daughter queens and drones. The bumblebees paid a high price for their immune response.

The study of insect immunity has become a hot topic in immunology. Major new discoveries about the underlying molecular and biochemical processes are made each year. Investigators have become particularly excited about tracing several elements of insect immune defenses to the system of innate immunity that goes back more than 450 million years. That innate system, exhaustively tested by evolutionary change, has played a crucial role in the more recent evolution of the induced immune defenses of mammals. To understand the evolutionary process, it will be essential to understand how the benefits and costs of various kinds of immune response were balanced against the prevailing parasitic threats. Bumblebees are a good living model in which to study those issues. Examining their struggles with disease promises to shed light on how and why immune systems evolved the way we observe. □

Bees loaded down with parasites may not appear sick, until their routine is disrupted. If forced to fly a bit farther for nectar, for instance, disease-ridden bees—initially unfazed by an infection—can die suddenly and in large numbers.

Oasis in the Everglades

A Florida wildlife refuge combines nature and nurture.

By Robert H. Mohlenbrock

Spider lily

Wetlands once covered much of the southern third of the Florida peninsula. Cypress swamps dominated the western part of the region and mangrove swamps the south coast. In the east lay a vast tract of water and sawgrass known as the Everglades. Prior to the nineteenth century, most of the settlement in southern Florida was confined to the strip of elevated land along the Atlantic coast. But by the 1800s people bent on farming began draining the Everglades by constructing canals and levees.

White water lilies bloom along a canoe trail in the Arthur R. Marshall Loxahatchee National Wildlife Refuge.

In 1934 Congress established the Everglades National Park to preserve the southern part of the original Everglades. North of the park and south of Lake Okeechobee, however, development continued. There, in the late 1940s, the U.S. Army Corps of Engineers began the establishment of three so-called water conservation areas, which further reduced the natural flow of water through the Everglades. The good news for the plants and animals that depended on the vanishing wetlands is that in 1951, the U.S. Fish and Wildlife Service and the State of Florida, under the Migratory Bird Conservation Act, turned one of the water conservation areas into a national wildlife refuge.

Still managed by the Fish and Wildlife Service, the Arthur R. Marshall Loxahatchee National Wildlife Refuge (named for the nearby town of Loxahatchee and in honor of a former employee of the Fish and Wildlife Service) covers more than 220 square miles. Most of the refuge is Everglades marsh bordered by levees. The water flow is managed to create marsh areas for waterfowl and other plant and animal species. Within the marsh are slightly elevated portions of terrain known as tree islands, which, true to their name, support the growth of trees. In addition, a 400-acre cypress swamp conserves the remains of a habitat that once extended all the way from Lake Okeechobee southeast to Fort Lauderdale.

Perhaps the most striking plants in the cypress swamp are the epiphytic bromeliads, which are members of the pineapple family. These gray or gray-green plants live on the branches and trunks of the trees, but they are not parasitic. Instead, their leaves absorb moisture and nutrient particles directly from the air, such as the remains of decaying leaves and the droppings of insects and birds. Spanish moss is the most familiar example, though a misnomer: it is not a moss but a flowering plant. Its small, yellow-green flowers are particularly fragrant after sundown.

The main entrance and the visitor's center of the refuge are located west of Boynton Beach, on Lee Road, off U.S. Highway 441. The only other public entry point (from Loxahatchee Road, also off route 441) is farther south, west of Boca Raton. The northern two-thirds of the refuge is closed to public use, but the rest provides ample opportunities for biking, canoeing, fishing, and hiking.

The refuge needs extensive management to maintain its present con-

dition. Periodic prescribed burning enhances the growth of certain native species and, perhaps more important, slows the growth of an aggressive invasive species, melaleuca. Furthermore, the refuge is a part of the Comprehensive Everglades Restoration Project, which is trying to return as much of the Everglades as possible to more natural conditions.

A major part of the project, under the direction of the Corps of Engineers, is to restore the natural flow of water. The South Florida Water Management District, which is manipulating water depths and flows under its jurisdiction and examining the responses of plants and animals, is conducting experimental studies at the refuge. The hope is to learn how to re-create, on a small scale, natural communities similar to the ones that still occur in the Everglades. Results from these studies will be applied to the larger Everglades complex.

HABITATS

Cypress swamp Visitors can see a good cross section of the cypress swamp by following a 0.4-mile boardwalk near the main entrance. The standing water along the way can be as much as two feet deep in rainy seasons, or it can vanish entirely in dry periods. Pond cypress is the dominant tree, but other species such as coco plum, red bay, and red maple also grow here. Native shrubs scattered beneath the canopy include buttonbush, dahoon holly, Virginia willow and wax myrtle. Among the invasive species found here and there are Brazilian peppertree, guava, laurel fig, melaleuca, Old World climbing fern, and strangler fig. Climbing hempweed, laurel greenbrier (bamboo vine), muscadine grape, pepper vine, saltmarsh morning glory, Virginia creeper, wild balsam pear, and other vines form dense entanglements.

Ferns range in size from the giant leather fern, with fronds as much as ten feet long, to the tiny water spangles and mosquito fern that float on the water. In between are cinnamon fern, giant sword fern, long strap fern, royal fern, and swamp fern. Apart from Spanish moss, epiphytic bromeliads include ball moss, Schultes northern needleleaf (with curved leaves) and southern needleleaf, and the rare spreading air plant. The showiest bromeliad is the wild pineapple, which produces small purple flowers emerging from red, usually yellow-tipped bracts.

Wild pineapple grows on trees but is not a parasitic plant; it gets its nutrients from moisture and particles in the air.

Marsh About a mile from the visitors center, a 0.8-mile hiking trail circles one of the marshes. Various plants are visible floating in the water or protruding above it. Among them are arrow arum, bull-tongue arrowhead, pickerelweed, water lettuce, white water lily, yellow water lily, and the invasive alligator weed. Growing in soggy soil but usually not in standing water are such species as alligator lily, bog hemp, camphor pluchea, seaside goldenrod, southern swamp crinum lily, sweetscent, Virginia saltmarsh mallow, and winged loosestrife.

Sawgrass The species is actually a sedge, not a grass, though at least it is aptly named for its notched leaf edges and their effects on unprotected legs. It often grows in dense colonies interspersed with dahoon holly and wax myrtle. This habitat typically borders tree islands.

Tree island Areas of the marsh slightly elevated above the water level usually have a dense growth of trees. Among them are buttonbush, coco plum, dahoon holly, and red bay.

Robert Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

For visitor information, contact:
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National Wildlife Refuge
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(561) 734-8303
http://loxahatchee.fws.gov

Stand and Deliver

Why did early hominids begin to walk on two feet?

By Ian Tattersall

Ask any paleoanthropologist what got humankind started on its unique evolutionary trajectory, and the reflex answer will almost certainly be "the adoption of upright bipedalism." And whatever the exact characteristics of the most ancient hominid may have been, there is no question that the adoption of upright locomotion on the ground was an epoch-making event for our hominid family.

The idea that *Homo sapiens* might be descended from some ancient apelike animal that walked around on its two hind legs goes back at least as far as Jean-Baptiste Lamarck's great *Philosophie Zoologique,* which appeared in the opening decade of the nineteenth century. And Darwin famously expressed a similar viewpoint in *The Descent of Man,* published in 1871. Darwin speculated that the importance of bipedalism was that it freed the hands from the demands of locomotion, thereby opening the way for toolmaking and other manual activities that make us uniquely human. If so, it took some time for our precursors to realize the potential of their upright posture: it is now clear that the origin of stone toolmaking postdated the acquisition of bipedalism by millions of years. Still, it is hard to resist the idea that bipedalism was a necessary condition for all that followed, even if it might not have been a sufficient one.

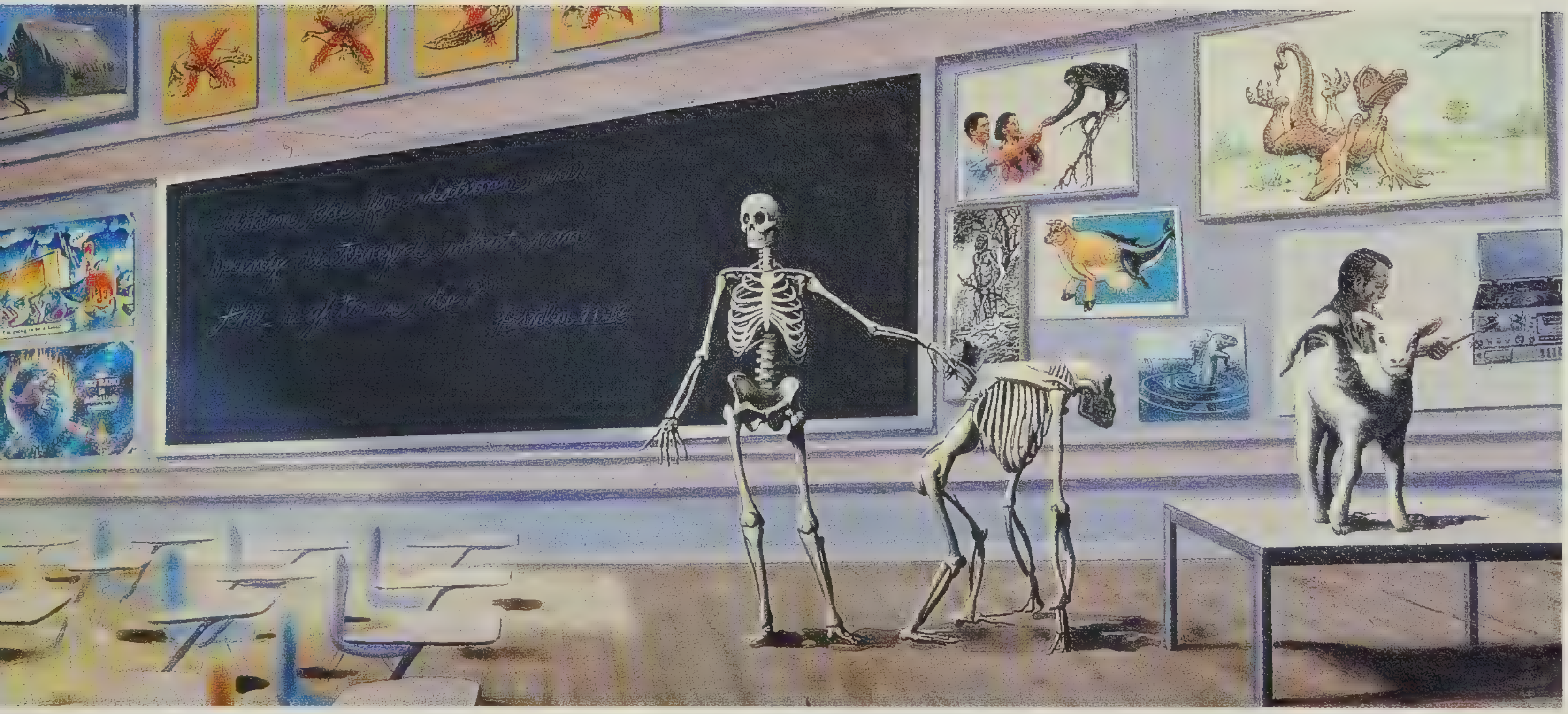
Since Darwin's day, paleoanthropologists have energetically sought the key to hominid erectness in many different places. Nearly always, though, these scientists have sought the Holy Grail of a single critical function: what exactly was it about being upright that gave early hominids the edge? For, given that teetering along on a single pair of feet is, to all appearances, hardly an optimal solution for a hominid whose ancestors almost certainly got around using four limbs, isn't it intuitively obvious that the particular advantage of walking upright on two limbs must have been an overwhelming one? And, at the very least, it's clear that upright bipedalism is not an automatic primate response to descending from the trees to live on the ground. Even patas monkeys, apart from ourselves the most committed-to-ground-dwelling of all living primates, have accomplished that shift by becoming even more specialized quadrupeds than their more arboreal ancestors had been before them.

So just what was going on when our ancient forebears, in a period of climate change that transformed their ancestral forested habitats in Africa into one of trees, shrubs, and grasses, started opting for upright, two-legged locomotion on the ground? There has been no dearth of suggestions, all based on adaptation to some aspect or another of ground-dwelling life. I have to confess here that I have long been suspicious of the profligate use of "adaptation" to simultaneously explain any and all evolutionary innovations. After all, any individual is made up of a whole host of features that one could describe as adaptations, whereas natural selection can only

vote up and down on the whole thing, warts and all. Still, there is no doubt that paleoanthropologists have come up with a whole host of terrific stories on the subject.

The first to describe a truly ancient biped was the Australian-born physical anthropologist and paleontologist Raymond Dart, in 1925. Dart understood that life on the predator-ridden open savannas would have been pretty dangerous for the relatively small, slow, and defenseless early hominids. He suggested that standing up would have enabled the creatures to peer over tall grass and spot dangerous animals at a distance. Other investigators have pointed out that an animal looks bigger when it stands up, which might help discourage predators from attacking it. Corroborating that idea, contemporary studies do seem to show that the predatory interest of big cats is more readily triggered by horizontal silhouettes than by vertical ones.

Those who prefer to look upon even our remotest ancestors as bush-league versions of ourselves have tended to side with Darwin. They see bipedalism as a mechanism for freeing the hands to carry food and other ob-



Alexis Rockman, *Creationist's Classroom*, 1998

jects back to home base, or as a way of making it easier for mothers to tote babies around. The most recent wrinkle in this hypothesis has been the suggestion (by male paleoanthropologists) that bipedal early hominid males used their free hands to carry food back to hapless females, whose baby-toting activities had dramatically curtailed their food seeking. This social behavior supposedly led in turn to such far-reaching consequences as pair-bonding, concealed ovulation, and the prominence of female breasts. The story has the undeniable attraction of tying bipedalism to a variety of human physical and social peculiarities, but it is no less controversial for that, and it has recently come under attack on a variety of grounds. Feminist anthropologists, for example, perhaps in retaliation for the perceived sexual slight, have directly blamed erect bipedalism on the appalling exhibitionist tendencies of males.

Lately, the bulk of the debate on the subject has focused on what might be called the thermoregulatory hypothesis. When you're out of the forest, the argument goes, you're out of the shade. With direct exposure to the tropical Sun, you need some way to cool down your body—particularly your heat-sensitive brain. Lacking specialized means for such cooling, hominids might have discovered that by standing up, they absorbed less of the Sun's heat (by minimizing the surface area exposed directly to the Sun's vertical rays). Furthermore, standing exposed the heat-radiating portions of their bodies to the cooling breezes that blow above ground-level vegetation. The idea is persuasive. The cooling effects dovetail nicely with such special human characteristics as sweating and the drastic reduction—compared with our ape ancestors—of body hair.

Lowly Origin: Where, When, and Why Our Ancestors First Stood Up
by Jonathan Kingdon
Princeton University Press, 2003; $35.00

Upright: The Evolutionary Key to Becoming Human
by Craig Stanford
Houghton Mifflin, 2003; $23.00

But the thermoregulatory hypothesis has by no means met with universal acclaim. An opposing camp argues that bipedalism is simply the most energy-efficient way for a hominid to get around on a flat surface. Careful calculations show that, under certain plausible conditions, ground-living hominids expend less energy moving around on two legs than they do on four. And the less energy you expend, the less food you need to find—another clear advantage.

Will the real reason for bipedalism please stand up?

In light of all the competing theories, some cautious weighing of their relative merits is clearly welcome. With excellent timing, here now are two books that, from rather different perspectives, devote themselves to the question of why hominids became upright, and to exploring exactly how that event may have shaped subsequent human evolutionary history. Intriguingly, both authors at least partly avoid the Holy Grail trap by developing quite complex scenarios. Each book, moreover, is a work of advocacy, with a clear and well-defined story to tell. That approach has the advantage of making both books highly readable. At the

. . . though, it leaves readers . . . little choice but to embrace or to spurn the arguments in their entirety, instead of offering readers a chance to shop around among the various components of each story.

Jonathan Kingdon commands a unique position at the interface of science and art. Not only has he made a substantial contribution to the scientific understanding of African mammal evolution and diversity; he has also enhanced our aesthetic appreciation of these animals through his graceful drawings and paintings. Predictably, his book *Lowly Origin* (a title drawn from Darwin's concluding statement in *The Descent of Man*) is enlivened by a generous selection of engaging illustrations. After listing at least thirteen distinct explanations that have been advanced at one time or another for hominid bipedalism (including all the ones mentioned above, and many more besides), Kingdon plumps for a multicausal argument, drawing on his extensive knowledge of African ecology and biogeography.

A. Demarle, *Evolution of Man from Mammals*, 1883

His scenario is a gradualist one. At first an ancestral quadrupedal "ground ape" slowly but smoothly progresses to a long-lasting squat-feeding phase. Whenever the creature forages on the forest or woodland floor, the trunk is held upright. Over millions of years the hind legs gradually assume the support of the upper body's weight. The resulting reduction of upper-body bulk improves the balance of the vertical trunk, until "four-legged movement cease[s] to be as efficient as simple straightening of the legs." At the same time, the pressure from predators on the ground becomes greater than it ever was in the trees, and so survival dictates greater social cooperation and more complex behaviors than ever before. Those developments enable the hominids to explore an increasingly broad range of environments, until they occupy the open savanna.

Governing this proposed sequence of events is the African environment in which the early hominids lived. Somewhat controversially, Kingdon contends that apelike human ancestors from Eurasia, originally of African ancestry, crossed back into Africa from Arabia about 10.5 million years ago. At that time the ancient Tethys Sea, which preceded the Mediterranean, was closing, permitting intercontinental contact between Africa and Eurasia. These apelike ancestors ultimately evolved to become chimpanzees and gorillas in the dense rainforests of central Africa, while, isolated on the other side of a relatively arid, treeless barrier, another group of descendants occupied the drier littoral forests of the African continent's eastern edge. Those latter primates eventually gave rise to the early hominids: creatures who were forced to change their ancestral feeding habits as a result of a changing environment. More specifically, they had to supplement the food resources available in the forest canopy with nutrients found on the forest floor.

Such a bald statement of Kingdon's complex and nuanced argument—which actually reaches back to explore our remotest primate origins, and beyond—does little justice to his elegant and thoughtful, if somewhat idiosyncratic, book. Whether or not Kingdon manages to convince you of his larger thesis, you will be provoked along the way by the many connections he makes. And just as important, *Lowly Origin* is a landmark for its thoroughness in integrating the story of human evolution (which he brings up to the present day) with that of the evolving landscapes and habitats of the African continent. What's more, Kingdon doesn't shy away from extrapolating the past to the future, painting an unattractive portrait of our species as a "niche thief" whose past success has depended on invading the ecological niches of others, but whose rapacious activities now threaten even its own future survival.

Craig Stanford, the author of *Upright*, is an accomplished primatologist who has specialized in studying the behaviors of African apes. His knowledge of chimpanzees, and, in particular, his field experience with them, inform much of his new book. Stanford points out that bipedal locomotion is a pretty bizarre way of getting around, with the clear implication that it calls for a pretty special explanation. He looks for that explanation in all the usual places, notably in the energetics of walking and the cooling of the brain, but he finds problems with them all.

One of the pleasures of Stanford's book is its splendidly gossipy account of recent research into the early history of hominid bipedalism. It dwells lovingly, for instance, on the prolonged sniping that went on between two

[illegible] of scientists, one based in the Midwest and the other on the East Coast, over the interpretation of the famous 3.2-million-year-old skeleton from Ethiopia known as Lucy. Stanford places himself somewhere in the middle. Reasonably, he rejects the East Coast scientists' assertion that Lucy's locomotor adaptation was "transitional." Just as reasonably, he accepts their (totally correct) conclusion that Lucy's bipedalism differed significantly from that of her successors of the genus *Homo*.

Oddly, in view of what Stanford has to say later on in his book, he also takes time to trash the idea that bipedalism was driven by environmental change. More significant, he argues, was that from the beginning hominids appear to have been ecological generalists. The key to their success was, and is, their ability to thrive in diverse environments. Yet despite his emphasis on environmental adaptability, he is still convinced that the hominids' unusual and implication-ridden form of locomotion was a response to *something,* and he is clearly concerned to discover a single underlying explanation for it. He finds it in meat eating.

Between 7 million and 8 million years ago, at the beginning of the scenario he reconstructs, some very early hominids "shuffled across the ground a bit between fruit trees." But as the climate became increasingly seasonal, and the grasslands expanded at the expense of the forest, natural selection would have favored those individuals who shuffled most efficiently across the enlarging open areas. That would have laid the groundwork for the success of the archaic bipedal hominids. They were the animals that could most effectively scavenge meat from carcasses they encountered in increasingly open areas, even as they hunted smaller game in forests and woodlands—much as some chimpanzees do today. Thus, despite Stanford's earlier insistence that hominids succeeded because they were generalists, he eventually falls back on environmental change as at least the initial external impetus for the multistage sequence of events that led to bipedalism.

Once a taste for meat had been acquired, everything else followed. "By three million years ago," he writes, "the whole equation of foraging energetics and diet had begun a fundamental shift." A "virtuous circle" had been established. More efficient upright walking fed back into increasing intelligence and social complexity, and those attributes led to ever more effective hunting. The last part of Stanford's short book is devoted to a once-over-lightly of the later hominid fossil record, illustrating how that dynamic has played out over the past couple of million years.

Did early hominids begin to move upright on the ground because their ancestors favored upright postures in trees?

Two very different books, then, presenting radically different scenarios for the origin of bipedalism in our lineage. But, significantly, what both books have in common is a firm belief in the gradual environmental molding of lineages, generation by generation, through natural selection. Indeed, both authors see natural selection as a driving force in human evolution—though Stanford correctly emphasizes that natural selection promotes the diversity of species, and stoutly denies that evolution is *toward* anything.

Yet natural selection can only work on novelties presented to it spontaneously; it cannot call anatomical innovations into being, however desirable they might appear. In nature, form has to precede function, for without form there can be no function. Yes, in retrospect bipedalism opened up a huge range of radical new possibilities for hominids. But evolutionists can hardly invoke those possibilities and their exploitation as explanations for the appearance of the new behavior.

So what can be said about how this fateful innovation came to pass? Well, it is clear that bipedalism arose quite early in hominid history, even if no one can be certain, in the strictest genealogical sense, that the earliest hominid was an upright biped. It is also pretty safe to conclude that the adoption of bipedalism was a formative event, with the profoundest possible consequences for later hominid evolution.

And there is a simple explanation, potentially testable by future fossil discoveries, for why early hominids began to move upright on the ground as their ancestral forests started to fragment. The explanation is that their own ancestors already favored upright postures in the trees, keeping their trunks erect during foraging, as many other primates do today. In other words, the early hominids were bipedal because they were already creatures that would have been most comfortable (if initially not totally at ease) moving upright on the ground.

If that was indeed the case, paleoanthropologists don't need to make difficult choices from the extensive menu of potential advantages that upright locomotion may or may not have offered the early hominids. Once our precursors had begun to descend from the trees, at the very least encouraged to do so by a changing milieu, they stood and moved upright simply because it was the most natural thing for them to do. Of course, once they had made this move, all the advantages of this new posture were theirs. And all of the liabilities too, for that matter.

Ian Tattersall is a curator in the Division of Anthropology at the American Museum of Natural History, and the author of numerous books, most recently The Monkey in the Mirror *(Harcourt, 2002).*

By Laurence A. Marschall

Ancient Wine: The Search for the Origins of Viniculture
by Patrick E. McGovern
Princeton University Press, 2003; $29.95

So old is the love of wine, and so rich in lore and legend, that its origins remain lost in the tangles of time. In Greco-Roman legend the god Dionysus is identified with bringing the art of wine making westward, from lands east of Persia. Biblical scholars who name Noah as the first cultivator of wine grapes describe him as settling down after the flood to become the first wine maker. He loved his work so much, according to the story, that he became the first town drunk.

In one of the most charming tales about the origins of wine, from ancient Persia, a fictitious King Jamsheed keeps jars of fresh grapes year-round, which he enjoys almost as much as he does his concubines. One of his consorts, suffering from severe headaches, mistakenly drinks from a jar containing spoiled fruit and falls into a deep slumber, from which she awakes refreshed and cured of her illness. She reports her experience to the king, who deliberately ferments his next batch of grapes, and the rest is what passed for history in those times.

In the wry judgment of a Persian poet of a later period, however, "Whoever seeks the origins of wine must be crazy." Clearly, the problem is not the lack of evidence but too much of it. Millions of clay pots that may have held intoxicating beverages are buried at countless archaeological sites. Pictures of drinkers and grape stompers decorate tomb walls and ceremonial vessels from sites throughout the ancient world. In the Fertile Crescent alone, so many clay tablets record the holdings of royal wine cellars and the commerce of wine makers that experts have translated and studied only a fraction of them so far.

And then there is a wealth of linguistic and cultural evidence. Dozens of living rituals, from the kiddush, or Sabbath "blessing over wine," which is central to Jewish life, to the communion wine of Christianity, attest to an ancient connection between wine and civilization.

Patrick E. McGovern, who heads the Molecular Archaeology Laboratory at the University of Pennsylvania Museum, brings a unique set of skills to this daunting study. He's a practitioner of molecular archaeology, an emerging field that applies the precision tools of microchemical analysis to the study of prehistoric artifacts. By measuring the precise mix of isotopes in a potsherd, for instance, he can identify its source in a specific clay deposit, and tie it to other pots whose locations trace out trade routes and cultural migrations that would otherwise remain unknown. Scrapings of residue from pots can identify key ingredients that once were stored inside them, even if only a few micrograms of material remain. The jumble of ancient remains can be sorted out to reveal hidden patterns of wine usage and distinctive variations in wine composition never before suspected.

With those tools McGovern and his coworkers have investigated wine cultures that go back well before written records. The ancient legends, it turns out, may have contained more than a "grape seed" of truth. The first wines, he believes, were made at least 7,000 years ago in the Caucasus, perhaps in the shadow of Mount Ararat, where Noah's ark supposedly came to rest. From there, not surprisingly, the art of wine making spread quickly: down the Tigris and Euphrates Rivers, along the coast of the Levant to Egypt, and west to Turkey and Greece.

Molecular archaeology can identify not only the source of the clay pots but the substances they once contained.

Fresco of putti pouring wine, Casa dei Vettii, Pompeii, first century

Many early wines, judging from the residues they left, were liberally mixed with pungent tree resins that probably served as preservatives in the absence of effective seals for containers. Few today except the Greeks, who continue to produce and consume retsina table wine, seem to regard the practice as anything other than an odd way to spoil a god-given drink.

The methods of McGovern and his colleagues have only begun to reveal the details of how grape cultivation and wine making developed in the ancient Mediterranean and the Near East. But their findings so far, summarized in the book, are already a rich treasury of lore on viticulture and on the drinking habits of the Assyrians,

Greeks, and other cultural groups in the region. This field of study is clearly destined to yield bumper crops in years to come, but McGovern's book will likely remain a standard in every serious wine-lover's library for a long time. To that achievement—and to glorious wine itself—let us raise our glasses high.

Mutants: On Genetic Variety and the Human Body
by Armand Marie Leroi
Viking Press, 2003; $25.95

Rosamond Purcell, *Twins Joined at the Rib Cage*, 1987

Don't let the bearded lady on the dust jacket fool you: this book is not a smarmy gallery of freaks and monsters. Armand Marie Leroi, a developmental biologist at Imperial College, London, has written an elegant study, filled with narratives from early medical literature and insights from the latest biomolecular research, on the subject of genetic variability and its manifestations in the developing human organism.

Not that the book isn't bulging with such oddities as flies born without eyes and babies born without irises—not to mention the person born with five nipples on one side and four on the other (a record). Leroi is also a gifted raconteur, and he's assembled a cast of fascinating and exotic characters. Josef Boruwlaski, an eighteenth-century Polish courtier whose memoirs introduce a chapter on human stature, stood just over three feet tall. He was a fixture at the courts of Europe, however, married well, raised a family, and died at the respectable age of 98. Carl Herman Unthan, born without arms in 1848, appears in a chapter on limb development. By age 20 Unthan was an established violin virtuoso, performing in Viennese concert halls with the great classical musicians of his time. In 1928, by then a naturalized citizen of the United States, he produced an autobiographical "pediscript" (so named because he had typed it out with his toes) that was published under the title *The armless fiddler*.

For every uplifting story, of course, there are many tales far more disturbing: conjoined twins sharing a single pair of legs; a man virtually frozen in place when his flesh turned to bone; people with single eyes, or with no eyes at all.

But Leroi's aim is to illuminate, not to titillate. Variability in the human species can be trivial, heroic, or tragic, but in all cases it is evidence of the coded blueprint in our genes, and of the way that blueprint is expressed in the developing organism. Although it is ethically impossible to experiment with the blueprint in the laboratory—turning genes on and off to see what happens—the outcome can be studied if nature does the experiment. Each mutation thus offers a glimpse of how one set of instructions, written in our genes, ends up forming a body.

Sometimes a mutant form arises from one alteration in a single gene. Leroi cites the descendants of an "exceptionally philoprogenitive" Chinese sailor, who in 1896 came ashore at Cape Town, South Africa, and settled in the Cape Malay quarter. All of his numerous progeny carry a mutation, on a gene called *CBFA1,* that affects cells that produce bone. And many of his descendants have inherited the mutation's traits, which include soft skulls, missing clavicles, and missing teeth—a fact that does not seem to affect their vitality: a 1996 survey turned up about a thousand people around Cape Town with the mutation, and they all speak with pride of their cartilaginous ancestor.

Other mutations involve multiple genes and work in ways far subtler

than do single-point mutations. Such characteristics as skin color, stature, longevity, and propensities for particular types of cancers often require several mutations to express themselves. Many variations in the human form, such as dwarfism or gigantism, can arise from such combined mutations. To make matters even more complicated, the DNA blueprint can be modified during the "construction" phase, and changing conditions in the embryonic environment can have far-reaching effects on later development. The thalidomide disaster of the 1960s, for instance, was caused by a drug prescribed to alleviate morning sickness. Inadvertently, though, it affected the growth of limb buds, and thousands of infants worldwide were born without the long bones of their arms or legs.

Although the entire human genome has been officially mapped since 2001, most of the ways it expresses itself are still unexplored. Leroi has written a guidebook to the territory, in which mutations are the landmarks that give an overview of the terrain. But it is clear that geneticists are only beginning to understand the connection between the dull sequences of C's, A's, G's, and T's in the genome map and the "real stuff" of bodies and minds. Leroi's book is a testament to both the ingenuity of organic life and the protean nature of what it means to be human.

Built for Speed: A Year in the Life of Pronghorn
by John A. Byers
Harvard University Press, 2003; $24.95

Travelers passing through the Great Plains called pronghorn antelope "prairie ghosts," as a testament to their speed and agility; an adult pronghorn can accelerate from zero to almost sixty miles an hour like a benzene-fueled dragster, and it cruises along effortlessly at forty-five miles an hour, easily outrunning anything that comes after it. Ever since the last lions and cheetahs died out in North America more than 10,000 years ago, there has been no serious predator on the continent that can match the pronghorn for speed. Today's hungry coyotes—the only mammals, other than you-know-who, that effectively hunt pronghorn—can only hope to snatch an occasional fawn in an unguarded moment.

John A. Byers is a field biologist who has spent almost a quarter of a century chasing pronghorn antelopes on Montana's National Bison Range. Byers observes his subjects with such patience that he can recognize individual faces the way most people recognize friends and family. He's read John

Pronghorn antelope fawn, built for racing and ruminating

James Audubon and John Muir, and, as he proves with stirring accounts of his experiences in big-sky country, he can spin a phrase with a skill worthy of those master wordsmiths. But Byers is a hard scientist as well as a lucid writer, and the image of the pronghorn that emerges from his research is not altogether a model of grace and beauty.

If you spied a pronghorn browsing among the summer grasses on the western plains of North America, you'd think they haven't a care in the world. But pronghorns maintain an exceedingly rigid dominance hierarchy that makes everyday life a constant battle. Females, Byers found, expend huge efforts bullying other prong-

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nd much of their time is taken jostling each other for the choicest napping spots. When one female gets pushed out of her spot by a more dominant individual, she'll wander around looking for an even weaker female to rouse—and so on, until everyone except the weakest has gotten in a lick. Young males challenge equals and inferiors with their horns, playfully at first—then, as they mature and begin to compete for mates, with injurious and even deadly intent.

It's even a bit misleading to describe them as "placidly browsing." Unlike bison or sheep, which simply mow down everything edible in their path, pronghorns are extremely fussy diners. Most of the time they aren't actually eating but nervously nuzzling plants, like a matron at a tea party looking for the choicest nibbles.

And yet, despite their choosiness, I wouldn't want to adopt their nutritional habits. Like cows and camels, they are ruminants, and true pronghorn serenity comes from burping up a recent meal, which has been fermenting in an outer stomach, and then chewing it all over and over again for an hour or more. The continuing mastication helps digest the tough material they take in, but it reminds me of one of those stomach-churning ads that run on the seven o'clock news.

What sounds even worse are the special snacks reserved for nursing mothers. After dining on fresh placenta, a pronghorn mom regularly chows down her fawn's feces for several weeks, apparently as a way to manufacture disease-fighting antibodies transmitted to her offspring through the mother's milk. "Natural selection," Byers writes, "can shape the brain to make anything that contributes directly to reproduction feel like fun." Yummy.

The dramatic climax of the pronghorn year, and of the book, is the rut. With winter approaching, pronghorn males each gather small harems of females into gullies and valleys on the prairie, trying to keep them out of sight of their rivals while they woo them. But the females will have none of it. They resist amorous advances time and again. Often, for several weeks, they move from one harem to another, sometimes with a male in pursuit, leaving behind the spilled blood of rejected suitors. Byers's account of one female's experiences is filled with white-knuckle suspense. Which male gets to mate with the lovely pronghorn ingenue? Will she fall in love with Archie's subauricular gland? Will an interloping yearling take her by force before Kareem gets a chance to charm her? It's the pronghorn equivalent of a bodice-ripper, and a natural history lover's delight.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

nature.net

Time Will Tell

By Robert Anderson

The movie camera is a marvelous tool in the hands of anyone, scientist or amateur, who is curious about time. The camera, after all, can control time—speed it up or slow it down—and so open a new and often surprising window on reality.

The best collection of time-altered movies on the Internet can be found at a site created by Red Hill Studios in Larkspur, California, in cooperation with the Science Museum of Minnesota in St. Paul. Appropriately, its address is playingwithtime.org. Select "to see and do" from the bar at the top of the page and then go to "gallery." On nine pages of choices, you'll find an eclectic mix of fascinating movies that go beyond Harold Edgerton's familiar stop-action work with drops of milk and apples pierced by bullets. The site also encourages viewers to create their own time-lapse movie projects.

At "Plants in Motion" (sunflower.bio.indiana.edu/rhangart/plantmotion/PlantsInMotion.html), maintained by Roger Hangarter, a biologist at Indiana University at Bloomington, is a collection of movie clips that make the growth of plants come alive. Choose from the category selections in the menu at the right, and watch the slender new stalks of sunflower seeds twisting toward the light, or the "sleep movements" of bean leaves responding to their biological clock.

Stephen Deban, a biologist at the University of Utah in Salt Lake City, has a page with movies showing how fourteen species of salamanders zap insect prey with their tongues (autodax.net/feeding movieindex.html). The Department of Biology at the University of Alberta runs an unusual instructional multimedia site (www.biology.ualberta.ca/facilities/multimedia). Click on the blue-lettered directions at the bottom of the page to see the time-lapse selections. You might want to skip a few if, like me, you're squeamish about bot flies, but don't miss the "Clam Escape Response."

I particularly liked a collection of movies from Erta Ale, an extremely photogenic volcano in Ethiopia (www.educeth.ch/stromboli/perm/erta/movies-en.html). Scroll down this page and you'll find five accelerated clips of the lava lake. Like a miniature version of Earth's plate tectonics, thin slabs of basalt crust jostle about, driven by the heat below. New crust is quickly formed, then subducted and recycled. Another site, at the NASA Goddard Space Flight Center (svs.gsfc.nasa.gov/search/Keywords/Glacier.html), speeds up the movement of glaciers, some of nature's most famous slowpokes, in a series of satellite images.

Astronomy, too, benefits from the miracle of time-lapse photography. On António Cicadão's "Lunar and Planetary Observation" page (www.astrosurf.com/cidadao/animations.htm) are beautifully presented solar and lunar eclipses, dancing satellites, and spinning planetary atmospheres. And at solarviews.com/eng/jupiter.htm#movie, click on "Animations of Jupiter" in the table of contents to view Jupiter's famous red spot. At the same Web site, another page (solar views.com/raw/nep/nepspot.mov), presents Neptune's dark spot.

Finally, the site of the Chandra X-ray Observatory has a remarkable movie, taken over a span of half a year, of the pulsar at the center of the Crab Nebula (Chandra.harvard.edu/photo/2002/0052/movies.html). Watch the spinning neutron star spew wisps and jets of matter and antimatter into the surrounding nebula.

Robert Anderson is a freelance science writer living in Los Angeles.

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MUSEUM EVENTS

EXHIBITIONS

Petra: Lost City of Stone

Through July 6, 2004

This exhibition tells the story of a thriving metropolis at the crossroads of the ancient world's major trade routes and of the technological virtuosity that allowed the Nabataeans to build and maintain Petra in the harsh desert environment.

In New York, Petra: Lost City of Stone *is made possible by Banc of America Securities and Con Edison. The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.*

Frederic Edwin Church, El Khasné, Petra, 1874. Oil on canvas

The Bedouin of Petra

Through July 6, 2004

Photojournalist Vivian Ronay's evocative color photographs document the Bdoul group of Bedouin tribes living around the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter

Through May 31, 2004

The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer.*

Vietnam: Journeys of Body, Mind & Spirit

Through January 4, 2004

Gallery 77, first floor

This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

LECTURES

Over the Edge of the World

Thursday, 11/6, 7:00 p.m.

Laurence Bergreen discusses Ferdinand Magellan's daring circumnavigation of the globe in the 16th century.

From Sea to Pharmacy

Thursday, 11/13, 7:00–9:00 p.m.

Are marine invertebrates and microorganisms the next source of anticancer and other drugs? Three top researchers in marine biomedicine discuss the latest findings.

This blue-green alga, *Hormothamnion*, produces peptides toxic to cancer cells.

The Lost Camels of Tartary

Tuesday, 11/18, 7:00 p.m.

John Hare, founder of the Wild Camel Protection Foundation, tells the compelling story of his expeditions in search of the elusive and critically endangered wild Bactrian camel.

Petra and the Middle East: Uncovering History's Earthquakes

Thursday, 11/20, 7:00 p.m.

Paleoseismology, the study of past earthquakes, provides new insights into the archaeological interpretation of Petra's fall. With Tom Rockwell, San Diego State University.

FAMILY AND CHILDREN'S PROGRAMS

Mosaic Tile Workshop

Sunday, 11/2 (Ages 7–9)
11:30 a.m.–12:30 p.m. or 1:30–2:30 p.m.
Sunday, 11/9 (Ages 4–6, each child with one adult)
11:30 a.m.–12:30 p.m. or 1:30–2:30 p.m.

Nature for Kids and Caregivers

Four Wednesdays, 11/12–12/10, 9:30–10:15 a.m. (Ages 2 and 3, each child with one adult)

Ocean Fridays

Four Fridays, 11/14–12/12
2:00–3:30 p.m. (Ages 5–7)

CHILDREN'S ASTRONOMY PROGRAMS

Solar System Adventures
Saturday, 11/1, 1:00–2:30 p.m.
(Ages 7–9)

Journey through the Solar System
Sunday, 11/9, 1:00–2:30 p.m.
(Ages 4–6, each child with one adult)

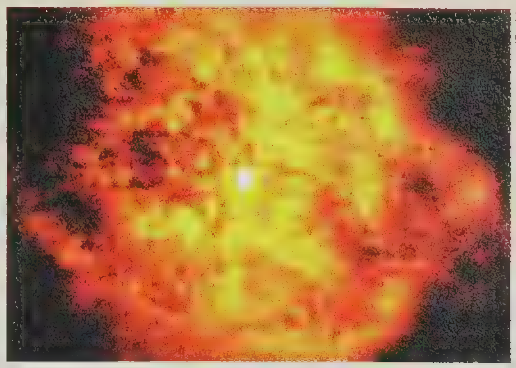
Space Explorers: Galaxies
Tuesday, 11/11, 4:30–5:45 p.m.
(Ages 10 and up)

Einstein for Everyone: Adventures in Light!
Tuesday, 11/18, 4:00–5:30 p.m.
(Ages 4–6, each child with one adult)

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe:
Black Holes and Quasars
Tuesday, 11/4, 6:30–7:30 p.m.
Redefine your sense of "home" on this monthly tour through charted space.

Truth and Beauty in Cosmology: Does the Universe Have an Aesthetic?
Monday, 11/10, 7:30 p.m.
With Chris Impey, University of Arizona.


NASA

The super-hot star WR124

Echo of the Big Bang
Monday, 11/24, 7:30 p.m.
The Wilkinson Microwave Anisotropy Probe, with Michael Lemonick, *Time* magazine senior science writer.

Celestial Highlights:
Winter Preview
Tuesday, 11/25, 6:30–7:30 p.m.
Find out what's up in the December sky.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 5 and under)

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Up the Chimney

Pipes of hot gas stream from superbubbles bursting out of the disk of the Milky Way.

By Charles Liu

The Milky Way has gas—and lots of it. Throughout the flapjack-shaped spiral galaxy we live in, there's at least half a quadrillion Earth-masses' worth of free-floating gas, most of it cold, neutral hydrogen just a few degrees above absolute zero. That's impressive, but it's still just a drop in the bucket on a galactic scale. Even excluding the ubiquitous dark matter that surrounds our galaxy [*see "Dark and Darker," by Neil deGrasse Tyson, page 18*], gas comprises only about 1 percent of the total mass of the Milky Way.

Still, that 1 percent packs a lot of astrophysical punch. As it flows and ebbs through the galaxy, interstellar gas serves as the raw material of creation—from the tiniest planet-bound life-forms to the grandest stars and nebulae.

Among the most spectacular patterns of gas flow are galactic chimneys—vast rivers of hot gas thousands of light-years long that can transport matter from the galactic disk into intergalactic space. Recently, a research group led by Naomi McClure-Griffiths of the Australia Telescope National Facility in Epping, New South Wales, has produced the most detailed map ever made of a galactic chimney, and it has shed new light on the fascinating movement of life-bearing gas into, out of, and throughout the Milky Way.

Imagine the stream of smoke rising from a just-extinguished candle. At first the smoke rises straight up, but then it starts to bend, spreading outward and upward. What the plume looks like a few seconds later depends on the local atmospheric conditions around the candle. Set the candle outdoors, on a breezy day, and the smoke blows away in a formless, ashy wind. Place it indoors, in a quiet room, and the smoke becomes a cloud of wispy filaments, swirling gently until they all blend into a screen of gray.

Gas moving around in a galaxy acts like candle smoke on a cosmic scale. Nearly all the gas in a typical spiral galaxy is confined to the galactic disk. Left undisturbed, the gas moves languidly around in the disk, settling into clouds made of softly swirling wisps and loops. But if a breeze blows through it—say, a stellar wind from a giant star nearby—the gas is driven outward. Depending on the strength and persistence of the winds, the gas gets piled up into new configurations: shells, bubbles, and walls.

In extreme cases, entire clusters of hot, massive stars combine to blow superwinds outward at more than a million miles an hour. The superwinds are then further energized when the most massive stars in the cluster self-destruct in titanic supernova explosions, releasing more energy in seconds than our Sun gives off in a billion years. The result: a "superbubble" forms in the surrounding interstellar space, rapidly expanding to hundreds or even thousands of light-years across. Inside the superbubble is very sparse, hot gas; all around it is a thin, dense shell of the cooler gas that was once drifting near the central star cluster. Eventually, a weak spot on the shell may rupture and the superbubble will burst, allowing the hot gas to stream out and causing the bubble to break up.

But if a superbubble does not burst, it can grow large enough to reach an edge "above" or "below" the galaxy's disk. There, with no more cool gas to pile up against its expansion, the superbubble pops out of the disk and into the much sparser galactic halo. The hot gas pours out of this hole, spewing energy and superheated particles into the halo and sometimes beyond, into intergalactic space. A galactic chimney is born.

Massive outflow of hot gas (red in this false-color image) emerges from the stellar disk of the starburst galaxy M82. More than 10,000 light-years long, the flow is driven by "winds" of particles and by supernovae from a large collection of massive stars within the galaxy. Similar, smaller-scale chimneylike structures erupt out of many galaxies, including our own Milky Way, into intergalactic space.

Well, that's one idea, anyway. But the model has its problems, and one of them comes from observations of gas in the Milky Way: there aren't enough hot, luminous stars in our own galaxy to generate the supernovae and superwinds needed to make all the shells, bubbles and galactic

chimneys that have been observed. Why should other galaxies act any differently? To patch up the galactic-chimney model, energy sources other than stellar winds have been suggested over the years, but none has been altogether satisfactory. Recently supercomputer simulations have suggested that stellar winds aren't even necessary; the random swirling of the gas can give rise to galactic chimneys by chance.

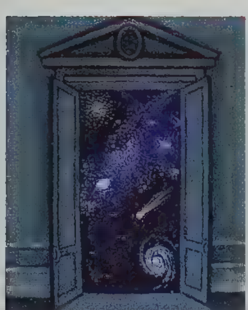
One way to address the problem is to look closely at a chimney's interior walls. If they are smooth, they're more likely to have formed by gentle, fairly random processes. But if the walls have fine structures, ripples, or intrusions, they probably reflect an interaction of hot, sparse gas with dense, cold gas—what you'd expect if a superwind were at work.

McClure-Griffiths and her collaborators made images of the galactic chimney designated GSH 277+00 +36; some images show structures more than 3,000 light-years long, others zoom in on details less than thirty light-years long. Studying the overviews, they noted that the chimney bifurcates, both at the top and the bottom of the superbubble, into vast "pipes" that direct the gas thousands of light-years outside the disk of the Milky Way and into the galactic halo. In the detailed images the investigators found countless loops, whorls, drips, and blips on the chimney's inside walls—like huge villi along a giant interstellar intestine. By themselves, the images don't resolve the question of how galactic chimneys form. But they do bring us one step closer to the answer—and afford us a beautiful glimpse of streaming, swirling star smoke.

Charles Liu is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

THE SKY IN NOVEMBER

By Joe Rao



Mercury spends most of November lost in the Sun's glare. But at month's end the planet may be visible through binoculars, low in the southwestern sky after sunset.

Brilliant Venus, at magnitude –3.9, shines low in the southwestern sky as darkness gathers. As the month begins, the planet sets less than an hour after the Sun. By month's end, though, the rapidly shortening days in the onrush to the (northern) winter solstice leave the planet setting more than an hour and a half after the Sun.

Orange-yellow Mars makes a good apparition this month; it's already high overhead at sunset and doesn't set until around 1 A.M. In early November Mars culminates, or reaches its highest point in the sky, at about 7 P.M.; by month's end it culminates an hour earlier. On the 1st Mars is 59 million miles from Earth and shines at magnitude –1.2. Among the stars, only Sirius is brighter. By the 30th the distance to Mars increases to 79 million miles, and the planet has dimmed to magnitude –0.4. The waxing gibbous Moon overtakes Mars on November 2 and 3.

Jupiter, in the constellation Leo, rises at about 1:45 A.M. at the beginning of November and just after midnight by month's end. The best time for viewing the planet this month is at approximately 5 A.M., when it shines brightly, high in the southeast.

Saturn, in the constellation Gemini, the Twins, rises at about 8:45 P.M. on the 1st and two hours earlier by the 30th. At midmonth the planet shines with a yellow-white light at magnitude –0.2. Its great ring system is tilted at 25 degrees to our line of sight, making it breathtakingly beautiful, even through a small telescope.

Less than six months after the lunar eclipse in May, the Moon will again undergo total eclipse, this time on the 8th. And again, eastern North America has the best view: those living east of a line running roughly from Medicine Hat, Alberta, to Corpus Christi, Texas, will be able to see the entire eclipse as the full Moon slowly climbs the eastern sky. Farther west, the eclipse is under way as the Moon rises; for skywatchers along the Pacific coast of California, the beginning of the total phase nearly coincides with moonrise.

Totality is brief, just twenty-five minutes. The Moon's disk should remain relatively bright (for an eclipse). The light-scattering effects of our planet's atmosphere could make for some colorful viewing. At the midpoint of totality the Moon's upper rim should look reddish brown; its middle should glow reddish orange; and its lower rim may be brighter orange—perhaps even tinged with a whitish "cap."

The Moon enters the Earth's shadow at 6:32 P.M. and leaves it at 10:05 P.M. Totality begins at 8:06 P.M. and ends at 8:31 P.M. Our satellite waxes full on the 8th at 8:13 P.M. It wanes to last quarter on the 16th at 11:15 P.M. and to new on the 23rd at 5:59 P.M. Just one minute later the Moon arrives at perigee, its closest point to Earth, 221,722 miles away. The Moon returns to first quarter on the 30th at 12:16 P.M.

Unless otherwise noted, all times are given in Eastern Daylight Time.

Captivated

By Meredith F. Small

I'm sitting on a bench in New York City's Central Park, waiting for the zoo to open. I have spent years observing macaque monkeys in the field, but these days I only teach and write about what they do, and I miss them. So whenever I'm in Manhattan, I hang out here with the snow monkeys *(Macaca fuscata).*

I've been visiting this troop for years. I have seen them in sunshine and snow; stood in the rain and watched them lick drops of wetness off their fur; held short business meetings in front of their exhibit; forced friends to meet me here. Unbeknownst to them, these furry gray monkeys from Japan have become my primate touchstone.

On this visit it's clear and sunny, and through the entrance gates I see the macaques jumping around their island exhibit. A path of rocks breaks the surface of the retaining pond that surrounds their enclosure, and a young female hops from one to another, leapfrogging over her troopmates as she goes.

Finally the gates open, and as I approach the group, my professional observing skills click in. By the time I reach them, my training as an observer—and that touch of magic I always feel in the presence of monkeys—has locked out the world; all that matters is the movement of these animals.

Today I count nine adults, one juvenile, and no babies. I know that fall is breeding season, and the females are signaling their fertility with red behinds. To my right a status interaction is unfolding—a female turns her rear to another female, indicating her lower position. I lean across the rail and get into the Zen of figuring out what these monkeys already know about each other: who is related to whom, how do they rank, which pair will be the next to mate?

My primatological reverie is interrupted by a crowd of visitors. I hear one woman call a male "she," and I'm compelled to correct her. "It's the shape of his face," I tell her, "and his size—and those bright red testicles." But I should know better than to be so patronizing, such a know-it-all. Several years ago, on one frozen January day, I asked some of the zoo's wild-animal keepers why the snow monkeys were indoors. After all, I told them, these monkeys are accustomed to crawling through snowdrifts in their native Japan. "If the pond froze over," they patiently responded, "the monkeys would simply walk out of the zoo." Humbled, I went to see the polar bear.

When I have the monkeys to myself again, I walk up the hill behind the exhibit and lean over the granite wall overlooking their enclosure, focusing on a pair of females. One is stretched out on a rock, arms and legs splayed in relaxation. Her eyelids droop. She is at peace. The other methodically moves a hand across her partner's belly, separating each strand of hair, gently touching each exposed patch of skin. Monkeys have done this to me, sitting on my shoulders with their handlike feet pressed against my neck, picking through my hair. I know it feels like heaven.

Snow monkey family, ink and water color on paper, Japan

Concentrating on the grooming females, I stretch my own arms across the wall and feel the reflected warmth of the sun seep up from the granite slab. I, too, let my eyelids droop in contentment. For a few precious minutes I pretend that I have done nothing for the past few months but watch this group, that we know each other intimately, observer and observed. Monkey noises, their barks and calls, fill my ears. The familiar, musty odor of monkey fur at close quarters fills my nostrils.

I am, once again, renewed.

Meredith F. Small is a writer and professor of anthropology at Cornell University.

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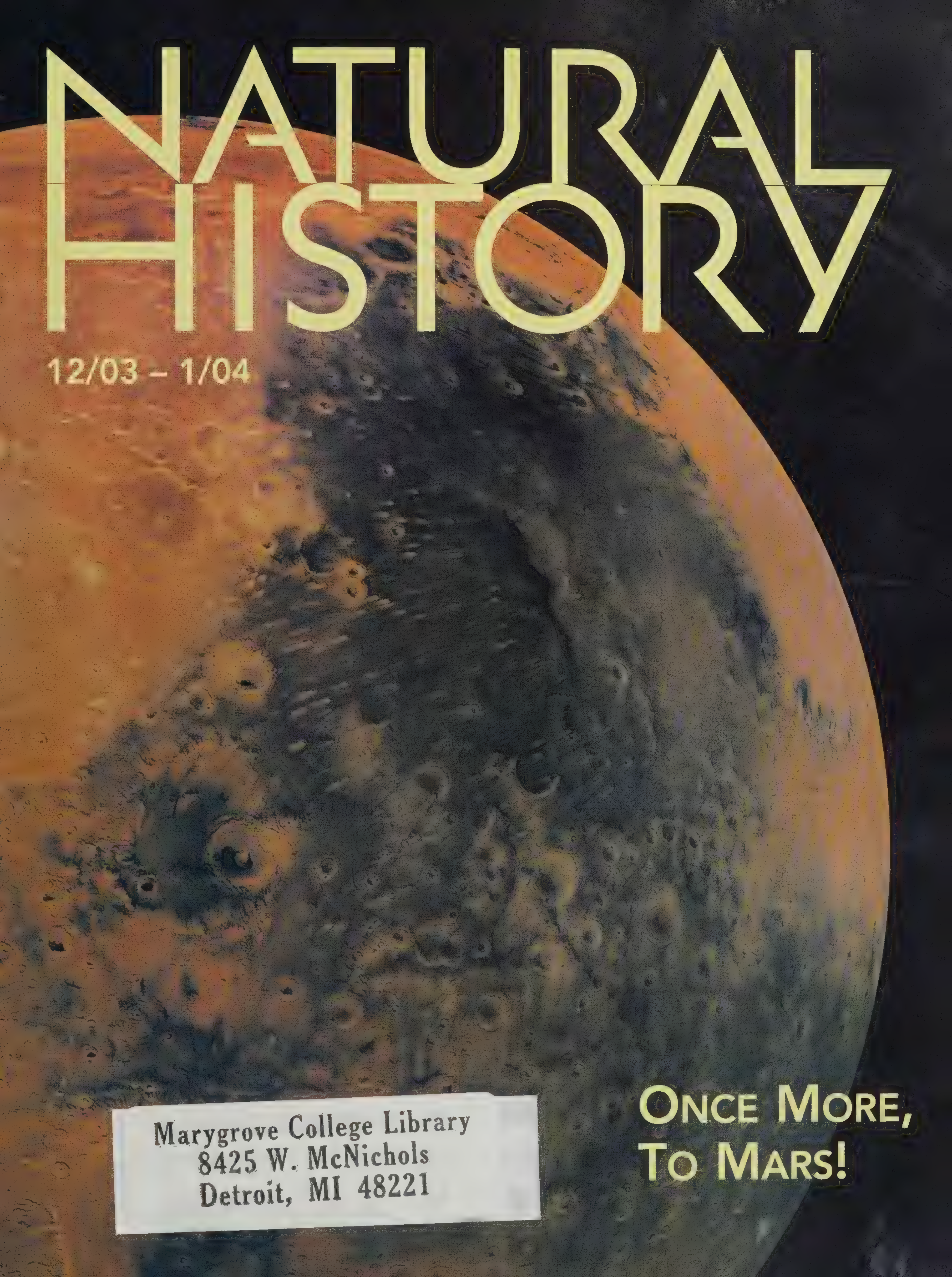

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NATURAL HISTORY

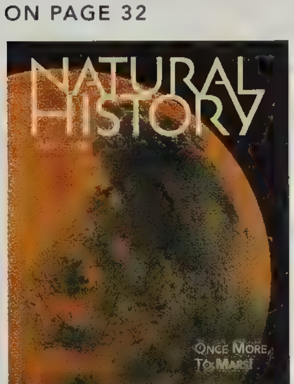
DECEMBER 2003/JANUARY 2004 VOLUME 112 NUMBER 10

FEATURES

COVER

Mars: Syrtis Major with wind streaks. Image made by a Viking orbiter.

STORY BEGINS ON PAGE 32



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DEPARTMENTS


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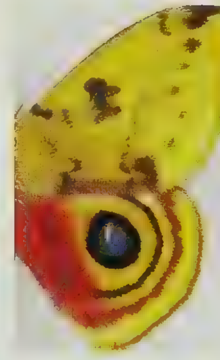
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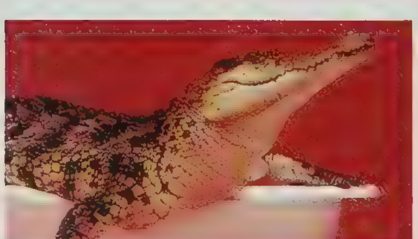
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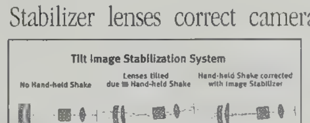

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Ah . . . Heaven!

Photograph by Art Wolfe

RAL MOMENT

eding pages

Thirty-four years ago this January, a snow monkey much like the bathing beauties pictured here made the cover of *Life* magazine. Japanese macaques *(Macaca fuscata),* as they are also known, have always been quick to soak up human culture. People are thought to have enticed monkeys into Japan's Yaen-Koen hot springs, near Nagano, about fifty years ago—apparently the monkeys' first dip in this natural hot tub after 500,000 years on Honshu Island. Other "people" skills, passed on to younger generations, include how to wash and salt potatoes with sea water, make snowballs, and trigger the automatic doors of supermarkets to shoplift food.

One ingenious troop of 150 snow monkeys got so good at stealing farmers' crops near Kyoto that the entire troop was banished to Texas in 1972. Over the years, the transplanted monkeys have proved their adaptability. Linda Fedigan, an anthropologist at the University of Calgary, in Alberta, says the Texas troop has learned how to eat prickly pear cactus and to warn each other about rattlesnakes and bobcats.

But some aspects of Japanese macaque culture, such as their matrilineal society, remain constant from place to place. Photographer Art Wolfe observed several mother-child pairs, including the one in the foreground here, ambling around the banks of the hot springs. They seemed relaxed and content simply to hang out together.

—*Erin Espelie*

Once More, To Mars!

One of the defining episodes in the public embrace of the Internet was the 1997 Pathfinder mission to Mars. Sojourner, the six-wheeled rover deployed by the Pathfinder lander, was the little robot that could. After Pathfinder shed the air bags that had softened the landing, Sojourner crept down a ramp to the martian surface, shook out its solar panel, and opened up its electronic eyes. Then, on command from radio signals that took eleven minutes to make the transit, Sojourner motored up to big rocks, probed them with its onboard instruments, and, most important, sent pictures of its out-of-this-world surroundings back to Earth. Pathfinder became the target of what was, at the time, the biggest "hit blizzard" in Web history. Millions logged on. Television came of age with wars, assassinations, and political conventions; the Internet came of age with a visit to Mars.

This January NASA is doing its long-awaited encore: landing two new rover missions, Spirit and Opportunity, on opposite sides of the Red Planet. But Spirit and Opportunity are only part of the space armada scheduled to take part in this winter's unprecedented martian exploratory extravaganza. *Mars Express,* launched by the European Space Agency, will reach Mars on Christmas day (*Mars Express* carries its own lander, Beagle 2). Japan's *Nozomi* spacecraft will reach Mars in January. As they arrive, all four spacecraft will find *Mars Odyssey* and *Mars Global Surveyor* already orbiting the planet. And once again, you can log on to the Internet, as Robert Anderson describes in his "nature.net" column "Mars on My Mind" (page 61), and follow the action as it happens.

• • •

One of the many extraordinary things I learned from Michael H. Carr's splendid preview of the scientific purpose of the rover missions, "What Became of the Water on Mars?" (page 32), is the critical role of a hot, roiling iron core to the "health" of a planet. The core of Mars cooled billions of years ago, and so the planet is magnetically dead. With a map and a compass to find your way around, you could just as well throw away the compass.

But surely that's a trivial price to pay for a planet-size piece of real estate. In fact, though, as Carr explains, one result of the loss of martian magnetism was the slow attenuation of its atmosphere. On Earth, the atmosphere and the magnetosphere deflect the charged particles that stream in from the Sun at a million miles an hour: the solar wind. But on Mars, the thin atmosphere and the loss of magnetism leave the surface exposed to the full brunt of the solar wind. Living on the martian surface would be like living inside an oversize television picture tube—except that you would be part of the screen, and charged particles would be raining down on your head. Large molecules such as proteins and DNA don't do well under heavy ion bombardment. In short, without a good lead umbrella, living on Mars would be cancer city. If you think Mars might offer a second chance for a species that fouls its own nest on Earth, think again.

—Peter Brown

CONTRIBUTORS

Trained in fine arts, nature photographer **ART WOLFE** ("The Natural Moment," page 4) published his first book, *Indian Baskets of the Northwest Coast,* just three years after earning a BFA from the University of Washington, in Seattle. In his twenty-five-year career he has worked on every continent and in hundreds of locations. Images from a recent photo safari in Africa can be previewed at his Web site www.artwolfe.com Wolfe's latest book, *Edge of the Earth, Corner of the Sky,* with essays by Art Davidson, focuses on landscape photography.

A native of Leeds, England, geologist **MICHAEL H. CARR** ("What Became of the Water on Mars?" page 32) has devoted a long career to the exploration of Earth's nearest neighbors. In 1962 he joined the United States Geological Survey. Since then, he has worked on the Apollo missions, on *Mariner 9,* and on the Viking and Pathfinder missions to Mars. Carr is a member of the team overseeing the operation of the two rovers, Spirit and Opportunity, scheduled to land on Mars this January. He is the author of *The Surface of Mars* (Yale University Press, 1984) and *Water on Mars* (Oxford University Press, 1996).

J. EMMETT DUFFY ("Underwater Urbanites," page 40), an associate professor of marine science at the Virginia Institute of Marine Science in Gloucester Point, Virginia (part of the College of William and Mary), has been a biophile since his undergraduate days in Mobile, Alabama, on the Gulf of Mexico. He has been investigating the social life of shrimps in the Caribbean for fifteen years and, more recently, the biodiversity and marine ecosystems of the Chesapeake Bay. Duffy is editing a book on crustacean behavioral ecology and social organization.

When **NYREE J.C. ZEREGA** ("The Breadfruit Trail," page 46) arrived at the New York Botanical Garden to do graduate work in systematics with assistant curator Timothy J. Motley, she wanted to study the origins and evolutionary relationships of a food plant. Motley introduced her to Diane Ragone of the National Tropical Botanical Garden in Hawai'i, who in turn introduced her to the garden's immense collection of breadfruit trees from regions around the Pacific Ocean. Zerega is currently a postdoctoral associate at the University of Minnesota, Twin Cities. Her article on human migrations and the origins of breadfruit in Oceania, coauthored with Ragone and Motley, will appear in 2004 in the *American Journal of Botany.*

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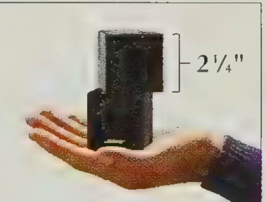

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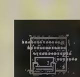

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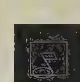

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As Marc J. Cohen writes in his review ["Crop Circles," 10/03], "few aspects of everyday life provoke such sharp disagreement as the emerging biotechnology of food." Barely mentioned by Mr. Cohen, the farmer is a major player in the battle over biotechnology.

In India, for example, farmers were critical in the struggle over whether to permit genetically modified (GM) cotton to be grown. The government tried to stop it, but a small company smuggled GM (Bt) cotton into the state of Gujarat, and for three years farmers grew it beside fields of traditional cotton. The secret was revealed in 2001 by a great bollworm infestation. Although the indigenous variety was devastated, the Bt cotton was unharmed. The government ordered the destruction of the illegal crop, but farmers had seen the overwhelming advantage of Bt cotton. The government soon approved its cultivation (S.A. Freed and R.S. Freed, "Green Revolution: Agricultural and Social Change in a North Indian Village," *Anthropological Papers of the American Museum of Natural History,* 85, 2002).

India is a democracy where 75 percent of the people live in rural areas. The farmers are voting with their plows.
Stanley A. Freed
American Museum of Natural History
New York, New York

MARC COHEN REPLIES: I was surprised that Stanley A. Freed felt that I had "barely mentioned" farmers in my review, since I identified boosting small-farmer productivity in developing countries as key to reducing world hunger, and as the main area in which biotechnology might help. Otherwise, I find his comments right on the mark. Indeed, Bt cotton has boosted the incomes of poor farmers else-

where in the developing world, including South Africa and China, while reducing pesticide use. The problem of how quickly the cotton pests will develop resistance to the Bt toxin remains a major issue in managing the technology. Research is also needed to determine the extent to which impoverished farm households are converting their income gains into better nutrition. In a case similar to the one Mr. Freed cites, soybean producers in Brazil engaged in civil disobedience on their farms, planting herbicide-tolerant seeds derived from biotechnology in defiance of a government ban. So there is no doubt that farmers in developing countries are major participants in the biotechnology debate.

Moonlighting

G. Jeffrey Taylor, in his article "Moonstruck" [9/03], refers to the Earth's tidal pull. But if the same side of the Moon always faces Earth, there should be no lunar tides. Shouldn't the force simply be Earth's gravitational pull? He also mentions mapping the Moon's magnetic field. But the lunar core is small and not liquid, so there should be no magnetic field. Could it be that what was mapped was the residual magnetization of portions of the lunar surface?
William J. Rihn
Laguna Beach, CA

G. JEFFREY TAYLOR REPLIES: Earth's gravitational pull creates a bulge on the side of the Moon nearer Earth and one on the opposite side. The Moon is commonly said to always present the same side toward Earth, but in fact it wobbles a bit. As the bulges move relative to the lunar surface, they create tidal forces in the rock. William J. Rihn is correct, it is not exactly "Earth's tidal pull." Nor does the Moon have a global magnetic field generated by an active core dynamo. There is a paleomagnetic field recorded in surface rocks (and also measured in lunar samples), which shows that the Moon once had such a global magnetic field. It existed before about 3 billion years ago and died out as the small core cooled.

Universal Clock

Neil deGrasse Tyson closes his column "In the Beginning" [9/03] with what seems to be a meaningless question: "What happened before the beginning?" Didn't time itself begin with the big bang?
David G. King
Southern Illinois University
Carbondale, Illinois

NEIL DEGRASSE TYSON REPLIES: The question, "What happened before the beginning?" may have no more meaning than the questions, "What lies north of the North Pole?" or "What time is it in Santa Claus's home?" Yes, we define time to begin at the big bang, but only as a convenience. Emerging theories provide for a multiple, perhaps infinite, number of universes, each with its own big bang, and, therefore, its own internal clock. What clock would we use to keep track of them all? If that question is meaningful, so too would be the question, "What happened before the beginning of our universe?"

The Best Defense?

I was surprised that one of the more infamous reasons for "pee" dumping by frogs wasn't mentioned in the "Endpaper" by Ryan C. Taylor ["Pees & Cues," 10/03]. If any urine makes contact with a creature's eyes, it will cause immediate burning and can cause the eyes to swell shut: a great defensive strategy if you're on a predator's menu.
Thomas Smilie
Lakeland, Florida

RYAN TAYLOR REPLIES:
In our study, Bryant Buchanan and I found that one benefit frogs may gain by dumping their bladder water is an increase in jumping performance. But that doesn't rule out other possible benefits. For example, when a frog dumps its bladder water, a snake may be temporarily distracted by chemical cues, allowing the frog to escape. But I am not aware of any studies demonstrating that the urine of frogs contains chemical irritants strong enough to cause eyes to swell shut. Snakes (probably one of the primary predators of squirrel treefrogs) have a scale covering the eye, which makes it particularly unlikely that frog urine would cause eye irritation. Mammalian predators such as raccoons readily prey on frogs with seemingly no ill effects.

When the Bough Doesn't Break

The lianas discussed by Adam Summers ["Extreme Forestry," 7/03-8/03] illustrate well the biomechanical problems faced by plants. Apart from the physical structure of a cell wall, the elasticity of tissues should be considered. For example, the aerial roots of parasitic strangler figs have flexible tissue, containing little lignin, that is woven into rigid wood fibers made up of cellulose microfibrils and a lot of lignin. The cells in the flexible tissue slip by each other with ease, a property that enables the roots to stretch like rubber rope, whereas the wood fibers resist a tearing force. Moreover, the sinuous shape of vines converts forces that might stretch the vine into shear forces, giving it spring-like elasticity.
Takashi Okuyama
Nagoya University
Nagoya, Japan

ADAM SUMMERS REPLIES:
Takashi Okuyama raises several good points. In particular, the overall structure of a plant plays an important role in its response to stress. Many vines look like a spring, and the coils absorb the energy of suddenly applied loads.

AMENDMENT: A few commonly repeated historical errors were unfortunately propagated in Richard Ellis's article, "Terrible Lizards of the Sea" (9/03). The type skull of *Mosasaurus hoffmanni* was unearthed between 1770 and 1774 (not 1780), and the army surgeon who had it brought to the surface was Johann Leonhard (not C.K.) Hoffmann (1710–1782). French revolutionary troops confiscated the skull on November 8, 1794; Napoleon's army did not carry it to Paris.

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

By Stéphan Reebs

Save the Earth

Probably the first thing concerned citizens think of when the word "endangered" pops up is an animal: the California condor, the giant panda, the bowhead whale, the leatherback sea turtle. But right under our feet may be something equally endangered: the soils of America. Of the 13,129 soil "series," or species, that occur in the United States, 4,540 are classified as "rare" (having a total area of less than 2,500 acres) or "rare-unique" (present in only one state, and having a total area of less than 25,000 acres). According to Ronald Amundson, a soil scientist at the University of California, Berkeley, and his colleagues, if more than 50 percent of a rare or rare-unique soil has been lost to such incursions as housing, highways, or agribusiness, the soil should be considered endangered.

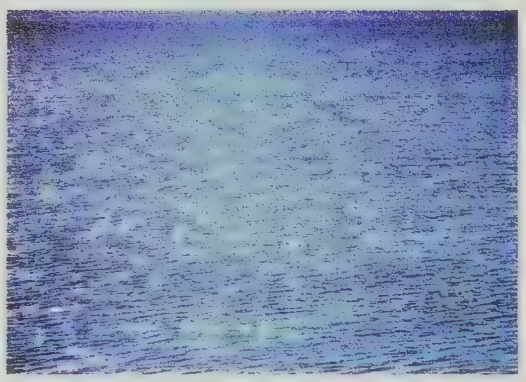
Some soils are getting scarcer in the United States.

The earth scientists caution that the diversity of soils on Earth today is the product of an unrepeatable combination of unique fauna and flora (many of them now extinct), as well as cyclic glaciations beginning about 1.6 million years ago. The resulting soil types—characterized by such features as depth, mineral composition, organic content, and texture—are therefore as unique as living species. Unusual soil types, moreover, are often the substrate for rare plants. Alter the soil, and the ecosystem changes.

By correlating a map of soil distribution with a satellite map showing land use, Amundson's team found 508 U.S. soils that are now endangered. California leads the list with 104, the most of any state. The rare soils of the country's agricultural heartland are in greatest jeopardy: more than 80 percent of Indiana's and Iowa's rare soils, for instance, are endangered. ("Soil diversity and land use in the United States," *Ecosystems* 6:470–82, October 2003)

Small Is Powerful

Sometimes small is ineffectual. But not when it comes to photosynthesis. The single-celled cyanobacterium *Prochlorococcus*—0.00002 inch in diameter—is the smallest known organism capable of photosynthesis. Yet numbers can make up for size: the bacterium is the dominant force in the production of organic material in the oceans.



Oceans are home to the smallest known photosynthetic organism.

You might think any organism that has to make all its own building materials from carbon dioxide, dissolved mineral salts, and light would need elaborate cellular machinery and a great many genes. If so, you'd be wrong. Alexis Dufresne, a biologist at the Biological Station of Roscoff in France, and an international team of investigators have sequenced the entire genome of the little powerhouse: one [illegible] chromosome. In it they counted just 1,884 genes for making proteins and forty more genes for making transfer RNA. (By comparison, an *Arabidopsis* plant—the "lab rat" of plant-genetics research—has some 25,000 protein-coding genes.) Many genes responsible for nitrogen assimilation, movement, cell repair, and response to stress in other cyanobacteria are absent in *Prochlorococcus*. That leads Dufresne and his coworkers to think they've found the smallest genome that can sustain life through photosynthesis alone. ("Genome sequence of the cyanobacterium *Prochlorococcus marinus SS120*, a nearly minimal oxyphototrophic genome," *Proceedings of the National Academy of Sciences* 100:10020–25, August 19, 2003)

Many Moons

Astronomers have long known that Mercury and Venus have no moons, Earth has but one, and Mars two. The count for the other planets in the solar system, however, is far from fixed. New moons are constantly being discovered, and the pace has picked up dramatically in recent years.

In the first nine months of 2003 alone, the tally of discoveries totaled twenty-one new satellites for Jupiter, one for Saturn, three for Uranus, and one for Neptune (also announced in 2003, but discovered earlier, were two more for Uranus and one more for Neptune). That brings the known totals to sixty-one for Jupiter, thirty-one for Saturn, twenty-seven for Uranus, and thirteen for Neptune.

Why have so many moons eluded detection until now? Simply put, they're small and far away. Some measure little more than half a mile across, and the newest discovery, a Neptunian moon, is almost 3 billion miles from Earth. But state-of-the-art cameras, together with sophisticated computer programs that can quickly calculate the orbits of moving specks of light, are lifting the veil on the stealthy satellites.

Besides being small, the new moons have irregular shapes and highly elliptical orbits. Astronomers think they started life as wandering asteroids—chunks of rock—and eventually got caught in the planets' gravitational fields. (Up-to-date tabulations at www.ifa.hawaii.edu/sheppard/satellites/, maintained by David C. Jewitt and Scott S. Sheppard, both astronomers at the University of Hawai'i, in Honolulu)

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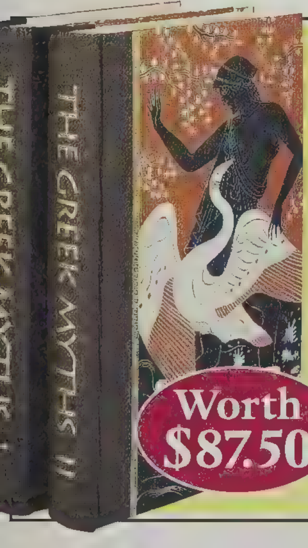

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Fair Is Fair

For more than two years Sarah F. Brosnan and Frans B.M. de Waal have been bartering with brown capuchin monkeys. Sometimes the animals get a fair deal, sometimes not. It's all part of a study the two primatologists are conducting at the Yerkes National Primate Research Center in Atlanta, on the evolutionary origins of the sense of fairness. Brosnan and de Waal propose that an aversion to inequity, regarded as a cornerstone of human cooperation, may have evolved in our primate ancestors.

In a recent experiment with pairs of captive capuchins, Brosnan handed a familiar token (a small rock) to one of the monkeys, then turned her own hand palm up. If the capuchin returned the token to Brosnan's hand within a minute, it got a reward. The same basic procedure was repeated nonstop with both monkeys, alternating between them, for twenty-five cycles.

Capuchin monkeys know when they're getting a raw deal.

The reward setup had four variations: (1) The reward was a piece of cucumber ("boring" food) for both monkeys in the pair—equal treatment for equal "work." (2) The "subject" got cucumber and its partner got a yummy grape, even though both monkeys did the same work. (3) The partner was absent, but a grape was placed in the partner's area as the subject watched. Then the subject not only had to work but also got cucumber in return. (4) The partner was given a grape without having done any work; the subject did the work but got the cuke—outrageously unequal treatment.

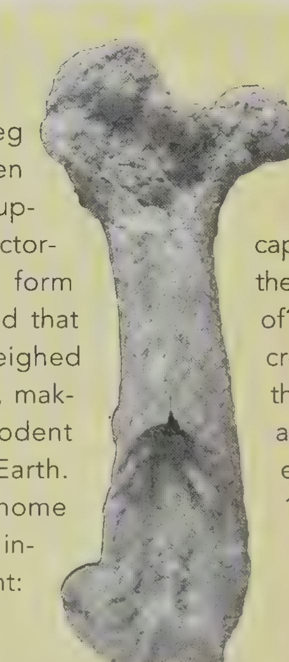
When treated unfairly, the five subjects often refused to return the rock token or tossed the cuke across the room. Occasionally a monkey settled for inequality, although sometimes it became more outraged as the unequal treatment persisted. ("Monkeys reject unequal pay," *Nature* **425**:297–99, September 18, 2003)

The Mouse That Roared

Anybody unlucky enough to have rodentophobia should probably not contemplate hopping a time machine back to Miocene-era Venezuela. It seems that not all rodents in those days were cute little balls of fur like your daughter's guinea pig. Indeed, fossils of *Phoberomys pattersoni*—an 8-million-year-old close relative of the guinea pig recently discovered in a paleontological treasure trove known as the Urumaco Formation—show that this animal had plenty of long teeth and weighed almost as much as a Holstein cow.

To determine the animal's weight, Marcelo R. Sánchez-Villagra, a paleontologist at the University of Tübingen in Germany, and his colleagues measured the cross section of its leg bones, unlikely to have been broader than necessary to support the rest of the body. Factoring in *Phoberomys*'s likely form of locomotion, they calculated that the critter must have weighed something like 1,500 pounds, making it by far the largest rodent ever to have roamed the Earth. South America is still the home of overblown rodents, in fact, including the largest one extant: the sheep-size capybara.

On the basis of fossil plants surrounding the remains, as well as the shape of the animal's teeth, Sánchez-Villagra's team suggests that *Phoberomys* fed on rough grasses in or near water, as capybaras still do. So what would the über-rodents have been afraid of? Possibly the forty-foot-long crocodiles that abounded in the same place and time. ("The anatomy of the world's largest extinct rodent," *Science* **301**: 1708–10, September 19, 2003)



Leg-bone cross section is a good indicator of an animal's weight.

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

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Gravity in Reverse

The tale of Albert Einstein's "greatest blunder"

By Neil deGrasse Tyson

Sung to the tune of "The Times They Are A-Changin'":

Come gather 'round, math phobes,
Wherever you roam
And admit that the cosmos
Around you has grown
And accept it that soon
You won't know what's worth knowin'
Until Einstein to you
Becomes clearer.
So you'd better start listenin'
Or you'll drift cold and lone
For the cosmos is weird, gettin' weirder.

—The Editors (with apologies to Bob Dylan)

Cosmology has always been weird. Worlds resting on the backs of turtles, matter and energy coming into existence out of much less than thin air. And now, just when you'd gotten familiar, if not really comfortable, with the idea of a big bang, along comes something new to worry about. A mysterious and universal pressure pervades all of space and acts against the cosmic gravity that has tried to drag the universe back together ever since the big bang. On top of that, "negative gravity" has forced the expansion of the universe to accelerate exponentially, and cosmic gravity is losing the tug-of-war.

For these and similarly mind-warping ideas in twentieth-century physics, just blame Albert Einstein.

Einstein hardly ever set foot in the laboratory; he didn't test phenomena or use elaborate equipment. He was a theorist who perfected the "thought experiment," in which you engage nature through your imagination, inventing a situation or a model and then working out the consequences of some physical principle.

If—as was the case for Einstein—a physicist's model is intended to represent the entire universe, then manipulating the model should be tantamount to manipulating the universe itself. Observers and experimentalists can then go out and look for the phenomena predicted by that model. If the model is flawed, or if the theorists make a mistake in their calculations, the observers will detect a mismatch between the model's predictions and the way things happen in the real universe. That's the first cue to try again, either by adjusting the old model or by creating a new one.

> *"Negative gravity" has forced the expansion of the universe to accelerate exponentially.*

One of the most powerful and far-reaching theoretical models ever devised is Einstein's theory of general relativity, published in 1916 as "The Foundation of the General Theory of Relativity" and refined in 1917 in "Cosmological Considerations in the General Theory of Relativity." Together, the papers outline the relevant mathematical details of how everything in the universe moves under the influence of gravity. Every few years, laboratory scientists devise ever more precise experiments to test the theory, only to extend the envelope of its accuracy.

Most scientific models are only half baked, and have some wiggle room for the adjustment of parameters to fit the known universe. In the heliocentric universe conceived by the sixteenth-century astronomer Nicolaus Copernicus, for example, planets orbited the Sun in perfect circles. The orbit-the-Sun part was correct, but the perfect-circle part turned out to be a bit off. Making the orbits elliptical made the Copernican system more accurate.

Yet, in the case of Einstein's relativity, the founding principles of the entire theory require that everything take place exactly as predicted. Einstein had, in effect, built a house of cards, with only two or three simple postulates holding up the entire structure. (Indeed, on learning of a 1931 book titled *100 Authors Against Einstein,* he responded, "Why one hundred? If I am incorrect, one would have been enough.")

That unassailable structure—the fact that the theory is fully baked—is the source of one of the most fascinating blunders in the history of science. Einstein's 1917 refinement of his equations of gravity included a new term—denoted by the Greek letter lambda—in which his model universe neither expands nor contracts. Because lambda served to oppose gravity within Einstein's model, it could keep the universe in balance, resisting gravity's natural tendency to pull the whole cosmos into one giant mass. Einstein's universe was indeed balanced, but, as the Russian physi-

cist Alexsandr Friedmann showed mathematically in 1922, it was in a precarious state—like a ball at the top of a hill, ready to roll down in one direction or another at the slightest provocation. Moreover, giving something a name does not make it real, and Einstein knew of no counterpart in the physical universe to the lambda in his equations.

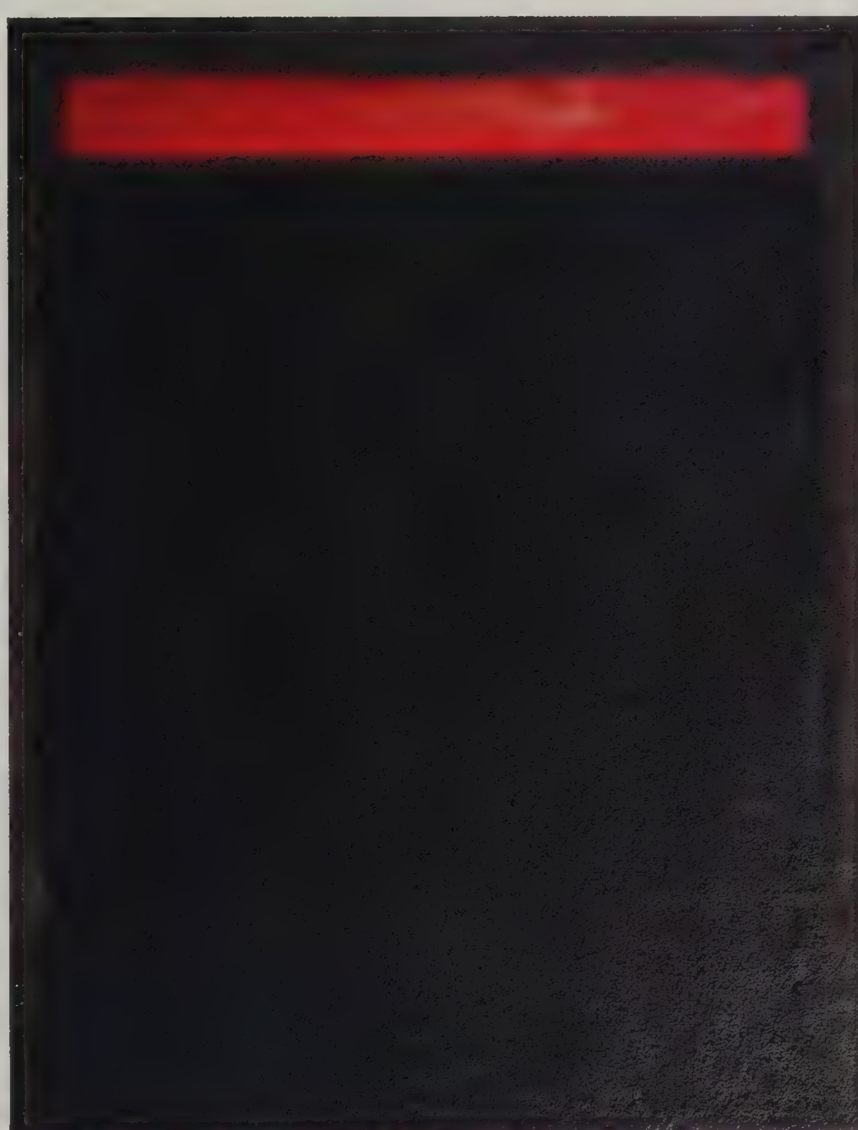
Einstein's general theory of relativity—called GR by verbally lazy cognoscenti—radically departed from all previous thinking about the attraction of gravity. Instead of settling for Sir Isaac Newton's view of gravity as "action at a distance" (a conclusion that discomfited Newton himself), GR regards gravity as the response of a mass to the local curvature of space and time caused by some other mass. In other words, concentrations of mass cause distortions—dimples, really—in the fabric of space and time. Those distortions guide the moving masses along straight-line geodesics, which look like the curved trajectories that physicists call orbits. John Archibald Wheeler, a physicist at Princeton University, put it best when he summed up Einstein's concept this way: "Matter tells space how to curve; space tells matter how to move."

In effect, GR accounts for two opposite phenomena: good ol' gravity, such as the attraction between the Earth and a ball thrown into the air or between the Sun and the Earth; and a mysterious, repulsive pressure associated with the vacuum of space-time itself. Acting against gravity, lambda preserved what Einstein and every other physicist of his day had strongly believed in: the status quo of a static universe. Static it was, but stable it was not. And to invoke an unstable condition as the natural state of a physical system violates scientific credo: you cannot assert that the entire universe is a special case that happens to be precariously balanced for eternity. Nothing ever seen, heard, or measured has acted that way in the history of science. Yet, in spite of being deeply uneasy with lambda, Einstein included it in his equations.

Twelve years later, in 1929, the U.S. astronomer Edwin P. Hubble discovered that the universe is not static after all: convincing evidence showed that the more distant a galaxy, the faster that galaxy is receding from the Earth. In other words, the universe is growing. Embarrassed by lambda, and exasperated by having thus blown the chance to predict the expanding universe himself, Einstein discarded lambda, calling its introduction his life's "greatest blunder."

That wasn't the end of the story, though. Off and on over the decades, theoreticians would exhume lambda—more commonly known as the "cosmological constant"—from the graveyard of discredited theories. Then, sixty-nine years later, in 1998, science exhumed lambda one last time, because now there was evidence to justify it. Early that year two teams of astrophysicists—one led by Saul Perlmutter of Lawrence Berkeley National Laboratory in Berkeley, California; the other by Brian Schmidt of Mount Stromlo and Siding Springs Observatories in Canberra, Australia—made the same remarkable announcement. Dozens of the most distant supernovas ever observed, they said, appeared noticeably dimmer than expected—a disturbing finding, given the well-documented behavior of this species of exploding star. Reconciliation required that either those distant supernovas acted quite differently from their nearer brethren, or else they were as much as 15 percent farther away than the prevailing cosmological models had placed them.

Not only was the cosmos expanding, but a repulsive pressure within the vacuum of space was also causing the expansion to accelerate. Something had to be driving the universe outward at an ever-increasing pace. The only thing that "naturally" accounted for the acceleration was lambda, the cosmological constant. When physicists dusted it off and put it back in Einstein's original



Mark Rothko, *No. 5 (Red, Black, and Brown-Black)*, 1963

equations for general relativity, the state of the universe matched the state of Einstein's equations.

To an astrophysicist, the supernovas used in Perlmutter's and Schmidt's studies are worth their weight in fusionable nuclei. Each star explodes the same way, igniting a similar amount of fuel, releasing a similarly titanic amount of energy in a similar period of time, and therefore achieving a similar peak luminosity. Hence these exploding stars serve as a kind of yardstick, or "standard candle," for calculating cosmic distances to the galaxies in which they explode, out to the farthest reaches of the universe.

Standard candles simplify calculations immensely: since the supernovas all have the same wattage, the dim ones are far away and the bright ones are nearby. By measuring their brightness (a simple task), you can tell exactly how far away they are from you. If the luminosities of the supernovas were not all the same, brightness alone would not be enough to tell you which of them are far from Earth and which of them are near. A dim one could be a high-wattage bulb far away or a low-wattage bulb close up.

Fine. But there's a second way to measure the distance to galaxies: their speed of recession from our Milky Way, a recession that's part and parcel of the overall cosmic expansion. As Hubble was the first to show, the expansion of the universe makes distant objects race away from us faster than the nearby ones do. By measuring a galaxy's speed of recession (another straightforward task), you can deduce its distance from Earth.

If those two well-tested methods give different distances for the same object, something must be wrong. Either the supernovas are bad standard candles, or our model for the rate of cosmic expansion as measured by galaxy speeds is wrong.

Well, something *was* wrong in 1998. It turned out that the supernovas are splendid standard candles, surviving the careful scrutiny of many skeptical investigators. Astrophysicists were left with a universe that is expanding faster than they had ever thought it was. Distant galaxies turned out to be even farther away than their recession speed had seemed to indicate. And there was no easy way to explain the extra expansion without invoking lambda, the cosmological constant.

Here, then, was the first direct evidence that a repulsive pressure permeated the universe, opposing gravity. That's what resurrected the cosmological constant overnight. And now cosmologists could estimate its numerical value, because they could calculate the effect it was having: the difference between what they had expected the expansion to be and what it actually was.

That value for lambda suddenly signified a physical reality, which now needed a name. "Dark energy" carried the day, suitably capturing our ignorance of its cause. The most accurate measurements done to date have shown dark energy to be the most prominent thing in town.

Direct evidence indicates that a repulsive pressure known as dark energy permeates the universe, opposing gravity.

The shape of our four-dimensional universe comes from the relation between the amount of matter and energy that inhabits the cosmos and the rate at which the cosmos is expanding. A convenient mathematical measure of that shape is usually written as the uppercase Greek letter omega (Ω). If you take the matter-energy density of the universe, and divide it by the matter-energy density required to just barely halt the expansion (known as the "critical" density), you get omega.

Because both mass and energy cause space-time to warp, or curve, omega effectively gives the shape of

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the cosmos. If omega is less than one, the actual mass-energy falls below the critical value, and the universe expands forever in every direction for all of time. In that case, the shape of the universe is analogous to the shape of a saddle, in which initially parallel lines diverge. If omega is equal to one, the universe expands forever, but only barely so; in that case the shape is flat, preserving all the geometric rules we all learned in high school about parallel lines. If omega exceeds one, parallel lines converge, and the universe curves back on itself, ultimately recollapsing into the fireball whence it came.

At no time since Hubble discovered the expanding universe has any team of observers ever reliably measured omega to be anywhere close to one. Adding up all the mass and energy they could measure, dark matter included, the biggest values from the best observations topped out at about 0.3. Since that's less than one, as far as observers were concerned, the universe was "open" for the business of expansion, riding a one-way saddle into the future.

Meanwhile, beginning in 1979, Alan H. Guth, a physicist at MIT, and others advanced an adjustment to big bang theory that cleared up some nagging problems. In brief, Guth explained why things look about the same everywhere in the universe. A fundamental by-product of this update to the big bang was that it drove omega toward one. Not toward one-half. Not toward two. Certainly not toward a million. Toward one.

Scarcely a theorist in the world had a problem with that requirement, because it helped get the big bang to account for the global properties of the known universe. There was, however, another little problem: the update predicted three times as much mass and energy as observers could find. Undeterred, the theorists said the observers just weren't looking hard enough.

At the end of the tallies, visible matter alone could account for very little of the critical density. How about the mysterious dark matter? Nobody knows what dark matter is, but observers knew there is five times as much dark matter as visible matter. They added that in as well. Alas, still way too little mass-energy. The observers were at a loss. "Guys," they protested, "there's nothing else out there." And the theorists answered, "Just keep looking."

Both camps were sure the other camp was wrong—until the discovery of dark energy. That single component raised the mass-energy density of the universe to the critical level. Yes, if you do the math, the universe holds three times as much dark energy as anything else.

A skeptical lot, the community of astrophysicists decided they would feel better about the result if there were some way to corroborate it. The Wilkinson Microwave Anisotropy Probe (WMAP) was just what the doctors ordered and needed. This NASA satellite, launched in 2001, was the latest and best effort to measure and map the cosmic microwave background, the big bang's blueprint for the amount and distribution of matter and energy in the universe. Astrophysicists can now say with confidence that omega is indeed equal to one: the matter-energy density of the universe we know and love is equal to the critical density. The tabulation? The cosmos holds 73 percent dark energy, 23 percent dark matter, and a measly 4 percent ordinary matter, the stuff you and I are made of.

For the first time ever, the theorists and observers kissed and made up. Both, in their own way, were correct. Omega is one, just as the theorists demanded of the universe, even though you can't get there by adding up all the matter—dark or otherwise—as they had naively presumed. There's no more matter running around the cosmos today than had ever been estimated by the observers. Nobody had foreseen the dominating presence of cosmic dark energy, nor

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So what is this stuff? As with dark matter, nobody knows. The closest anybody has come to a reasonable guess is to presume that dark energy is a quantum effect—whereby the vacuum of space, instead of being empty, actually seethes with particles and their antimatter counterparts. They pop in and out of existence in pairs, and don't last long enough to be measured. Their transient existence is captured in their moniker: virtual particles.

But the remarkable legacy of quantum mechanics—the physics of the small—demands that we give these particles serious attention. Each pair of virtual particles exerts a little bit of outward pressure as it ever so briefly elbows its way into space. Unfortunately, when you estimate the amount of repulsive "vacuum pressure" that arises from the abbreviated lives of virtual particles, the result is more than 10^{120} times bigger than the value of the cosmological constant derived from the supernova measurements and WMAP. That may be the most embarrassing calculation ever made, the biggest mismatch between theory and observation in the history of science.

Are we missing some basic pieces of the earlier universe? What part of the cosmic saga has been erased?

I'd say astrophysicists remain clueless—but it's not abject cluelessness. Dark energy is not adrift, with nary a theory to call home. It inhabits one of the safest homes we can imagine: Einstein's equations of general relativity. It's lambda. Whatever dark energy turns out to be, we already know how to measure it and how to calculate its effects on the cosmos.

Without a doubt, Einstein's greatest blunder was having declared that lambda was his greatest blunder.

A remarkable feature of lambda and the accelerating universe is that the repulsive force arises from within the vacuum, not from anything material. As the vacuum grows, lambda's influence on the cosmic state of affairs grows with it. All the while, the density of matter and energy diminishes without limit. With greater repulsive pressure comes more vacuum, driving its exponential growth—the endless acceleration of the cosmic expansion.

As a consequence, anything not gravitationally bound to the neighborhood of the Milky Way will move away from us at ever-increasing speed, embedded within the expanding fabric of space-time. Galaxies now visible will disappear beyond an unreachable horizon. In a trillion or so years, anyone alive in our own galaxy may know nothing of other galaxies. Our—or our alien Milky Way brethren's—observable universe will merely comprise a system of nearby stars. Beyond the starry night will lie an endless void, without form: "darkness upon the face of the deep."

Dark energy, a fundamental property of the cosmos, will, in the end, undermine the ability of later generations to comprehend their universe. Unless contemporary astrophysicists across the galaxy keep remarkable records, or bury an awesome time capsule, future astrophysicists will know nothing of external galaxies—the principal form of organization for matter in our cosmos. Dark energy will deny them access to entire chapters from the book of the universe.

Here, then, is my recurring nightmare: Are we, too, missing some basic pieces of the universe that once was? What part of our cosmic saga has been erased? What remains absent from our theories and equations that ought to be there, leaving us groping for answers we may never find?

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City.

Good Whale Hunting

Two tantalizing Russian reports take the author on a quest to the Antarctic, in search of two previously unrecognized kinds of killer whale.

By Robert L. Pitman

New killer whale on the block? Unlike the killer whale familiar to aquarium visitors, the kind pictured above, in the southern Ross Sea, lives in the Antarctic pack ice. To find their way from one breathing hole to the next, the whales "spyhop," lifting their heads above the surface to get a better view before picking their way through the dangerous and shifting channels of pack ice.

They always remind me of witch's hats—a little bit of Halloween in the winter wonderland. Looking across a flat plain of frozen Antarctic sea ice, I watch as a herd of killer whales swims along a lead—a long, narrow crack in the six-foot-thick ice. The fins of the males are black isosceles triangles, five feet tall, and they look like a band of trick-or-treaters coming our way. I am on board the U.S. Coast Guard icebreaker *Polar Star* as it back-and-rams the frozen ocean to open up a fourteen-mile-long channel into McMurdo Station, fifty feet at a whack. The National Science Foundation has offered me a bunk on board the vessel while I study the killer whales that inhabit the pack ice of the southern Ross Sea.

In the early 1980s, whalers from the former Soviet Union, presumably in the mood for some new product testing, slaughtered more than 900 Antarctic killer whales in one season. Workmen on the flensing deck of the factory ships, where the blubber and meat is stripped off the animals, quickly realized that two quite different kinds of killer whale were being hauled up the slipway for processing. The differences were so striking that two groups of Soviet investigators independently described new species of killer whale from the Soviet catch data—though it is not clear from their accounts whether they were describing the same, or different, new species.

In any event, one group's description was too vague, and a holotype, or museum reference specimen, was not designated, so the description has to be scientifically ignored. The other description, however, by Alfred Berzin and Vladimir Vladimirov, both cetacean biologists at the Pacific Research Institute of Fisheries and Oceanography in Vladivostok, Russia, provided some fairly solid evidence that there might be two species of killer whale in Antarctica. (Unfortunately, although Berzin and Vladimirov designated a holotype specimen, it has subsequently been discarded.) One species, of course, is the familiar denizen of SeaWorld, a large black-and-white form that lives throughout the world's oceans but does not penetrate into the Antarctic ice. It travels in herds of between ten and twenty animals and feeds almost exclusively on marine mammals, particularly Antarctic minke whales *(Balaenoptera bonaerensis)*. This form is likely just a summer visitor to Antarctica.

Berzin and Vladimirov reported that the second form, which they provided a name for—*Orcinus glacialis*—in their belief that the species was new to science, lives mainly in the pack ice, where it may be a year-round resident. It occurs, they said, in herds that sometimes number in the hundreds of individuals. The animal is between three and five feet shorter than *O. orca*, with markings that are yellowish in color instead of white, and feeds almost exclusively on fish. The yellow coloration is presumed to be from an infestation of diatoms. Caused by microscopic phytoplankton that occur in polar waters and on the underside of ice, the coloration is a characteristic of

all forms of pack-ice killer whales, but not of *O. orca*. The pack-ice animal also has much smaller teeth than *O. orca,* which may be related to its diet of fish. Although the Russian description of *O. glacialis* is in many ways convincing, most cetacean biologists have not accepted the validity of a second species, much less a third one (the species described so vaguely by the second group of Soviet investigators). Yet the evidence is tantalizing enough that I have come to the Antarctic Ocean to see for myself.

As the *Polar Star* sits motionless at the head of the channel we have just created, killer whales that were swimming along the edge of the pack ice are now moving toward us through the broken ice that has filled in behind the ship. As they enter the dense pack ice, their heads start sprouting up through the shattered ice like giant black-and-white tulips. They are "spyhopping": hovering above the surface for a second or two, where they seem to be eyeing our vessel and the ice in between us and them, and then easing straight back down into the water.

It dawns on us that the entire herd of thirty or so animals are leap-frogging through the pack ice and moving toward the stern of our ship, seemingly interested in the pool of open water that our prop wash has created. Sometimes individuals pop up several times in the same spot, apparently looking ahead for the next open water before they proceed. Their heads jut high out of the water, maybe six feet or so, and they crane their necks to scan the surface in search of the next breathing hole. Getting stuck under the ice would spell certain death for these air-breathers, and they need to carefully plan their moves.

As they close in around us, we notice another intriguing behavior: just before the whales break the surface, the sea boils vigorously and a perfect circle of clear water opens up above them. Most of the broken ice behind the ship is tightly packed, and the shards are hard and often sharp. The adult whales are forcefully exhaling just before surfacing, opening up a breathing space several feet across so they won't cut or scrape their sensitive skin on the ice debris. Whale calves also surface in the ring of open water, right next to their mothers.

Later that evening a different group of twenty killer whales appears to be socializing in a large open pool in our channel. We count as many as twelve individuals that seem to be practicing synchronized swimming: they charge around at high speeds and make sharp turns, all the while keeping in tight shoulder-to-shoulder formation. One animal is swimming upside-down at the surface when an adult female strikes it midbody from below, propelling it sideways and ten feet out of the water. It looks like tons of fun.

Pack-ice killer whales of the Ross Sea, probably the form to which Russian biologists gave the new species name Orcinus glacialis, *are also partly distinguishable by a "cape"—a dark coloring on the whale's back that is distinct from the lighter shading below, typified by the animal shown here. The cape is not present in* O. orca.

A few days later we find another herd of killer whales beyond the pack ice. Captain Dave MacKenzie gives me the okay to go over the side in a launch, along with fifteen or so curious Coasties. Most of the crew truly enjoy being outside—if only because it is the only time they are allowed to smoke while on board the *Polar Star.* Probably none of them has ever been right up close to a whale in the wild before, and they aren't quite sure what to expect. Some of the killer whales are almost as long as our twenty-five-foot launch, and there is concern on the faces of the younger crew members, some only recently out of high school. Someone asks me if I am going to be killing any whales today, and I realize I should have given them a little talk before our initial outing.

The launch is rather boxy looking, but somehow it churns ahead at forty knots. We quickly catch up to the herd. These whales are the kind I came here to find: they are smaller than the usual form; and they have a distinctive "cape," or darker coloring on the back, in contrast to the lighter shading below, and yellowish instead of white patches. We are lucky to find them in open water. It is a fairly large group, maybe fifty-five individuals, including several adult males and some very young calves. They are scattered over a mile or so, in subgroups of between one and ten animals. My hope is to photograph as many individuals as I can from close range, to confirm that they are the pack-ice types. I also plan to collect some biopsy samples, which will enable us to compare these animals genetically with killer whale populations elsewhere in the world, to determine just how distinct they are. If the whales are cooperative, we'll get our photos and samples; if they're evasive, all we'll get is wet.

To collect the biopsy samples, I have brought two crossbows along: a small crossbow if the whales allow us close access, and a compound crossbow in case I have to call long distance, a hundred feet or more. The darts I shoot are regular aluminum-shaft arrows, but they have a float attached to the business end and a small

cutting head threaded onto the tip. The cutting head extracts a plug of tissue about the size of a pencil eraser.

Normally when I shoot, the dart bounces harmlessly off the back of the animal and lands floating on the surface, where we motor over and pick it up. When I describe the biopsy operation to the launch crew, some seem uncomfortable with the idea at first, but that only lasts until they see the dart bounce off a whale like a soda straw off a truck tire. The darting itself usually has little noticeable effect on the whales and they are often more annoyed at the launch buzzing around among them, so we try to take care of business quickly and then leave them alone.

A lot is riding on this sortie—months of planning are coming to a head. The weather is sloppy, and subfreezing spray douses us whenever we head upwind (apparently a favorite direction for killer whales!). Clearly the weather is not going to give us much of a break. I just hope the whales will cooperate. Although I have talked to the helmsman in advance about how to approach the whales, I still have to shout instructions back from my lookout in the bow, over the din of the engine and the pounding of our launch against the waves. Our operation is akin to calf-roping from a jet ski, and our young driver begins a little apprehensively. But goading from the other crew members onboard carries the day, and soon she's charging into the fray.

The whales are moving along, all in the same direction and at a fairly fast clip; they seem to have an appointment somewhere. That makes it relatively easy for us because what we plan to do is come up directly behind them, traveling only slightly faster than they are, and then swing out sixty feet or so to the side. That maneuver will get us broadside to the whales and give us nice targets for the camera and crossbow, with minimal disturbance to the herd.

As we move to within 300 feet of our target subgroup, some of the whales slightly alter the way they swim, but clearly in response to our presence. Their surfacing rhythm changes, and some animals veer away from the group a bit as they dive. Some of the females rein in their calves. But ultimately the whales have no major reactions to us, and our prospects look good. I pick out a pair of adult males for the driver to sidle up to.

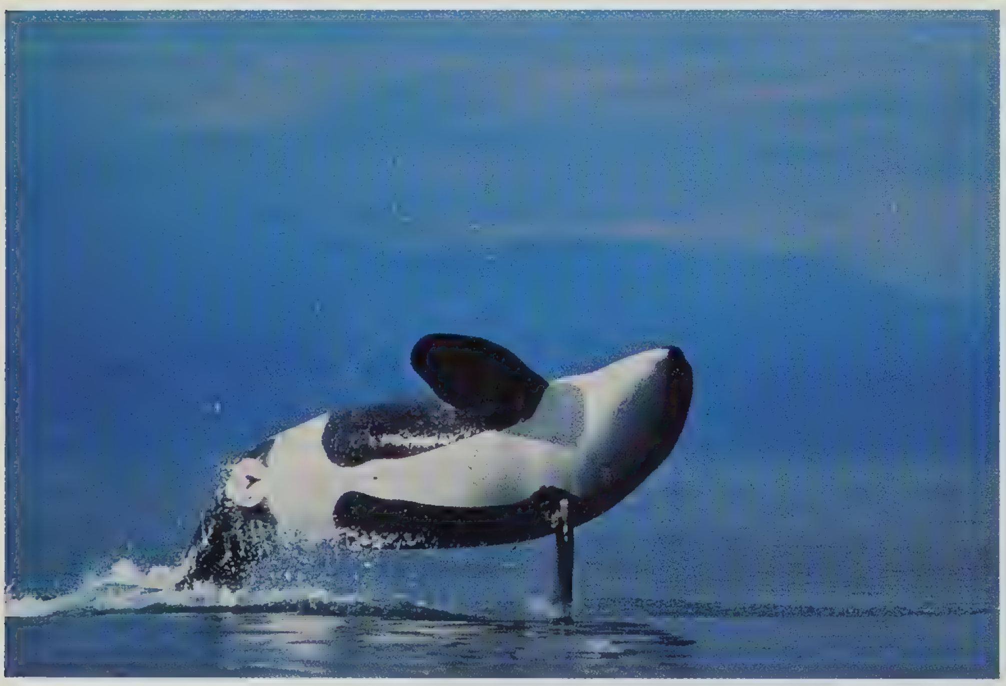
I fire a dart that seems to loft for an eternity. But it finds its mark, then bounces off the back of the nearest whale. As frequently happens when two whales travel close together, the companion whale responds to the darting the instant the target whale is hit. This companion gives a quick flick of the tail—just a little reminder that whales and dolphins perfected high-speed, wireless communication millions of years before human beings even began doodling on cave walls.

I wave wildly at the driver for us to go back and pick up the dart—she hasn't seen me shoot and is still throttling hard forward, trying to keep up with the whales. We finally do a hard turn to starboard and circle back to where my Day-Glo orange dart is bobbing in the middle of a slick left by the diving whale. As we ease in for the pick-up, I can see a tiny nub of blubber protruding from the end of the tip. We have the sample. The first one is always the most important.

We catch up with the herd again, trying to take more photographs and samples. And as we do, our boat crew looks on in stunned awe as four-ton killer whales lunge alongside, within ten feet of our launch. For sheer size and predatory power, the killer whale is probably the closest thing to a living *Tyrannosaurus rex* on Earth today. But there is also a remarkable beauty about the beasts: they fairly gallop, like sleek thoroughbreds, through the velvety cold Antarctic water, their black and white bodies a glistening collage of wet inner tube and white porcelain.

We spend almost two hours with the whales, half of it as my shipmates hold me by the ankles while I dangle over the side retrieving darts. (In my haste I forgot to bring a net, but fortunately the Coast Guard has a knack for pulling people out of the water.) Still, we have a fine outing: nine tissue samples and three rolls of exposed film.

As in nearly all biological investigations, simple questions rarely have sim-



O. orca, the most familiar killer whale, is the largest member of the dolphin family. When the animal visits Antarctic waters, it probably does so only as a summer migrant, feeding in open water seaward of the ice pack. The whale is usually jet-black, with a white underbelly.

[illegible]vers, and the taxonomic status [illegible]tic killer whales—How many species are there?—is no exception. All killer whales have a white pigmented area behind the eye called an eye patch. Around McMurdo, in the southern Ross Sea, I found that the killer whales in the pack ice have small, slanted eyepatches, and they apparently feed mainly on Antarctic toothfish *(Dissostichus mawsoni)*, a fish that grows to more than six feet long and more than 250 pounds.

The following year, however, near the Antarctic Peninsula on the other side of the continent, I found that the killer whales patrolling the pack ice are quite different: they have large eye patches that aren't slanted, and they prey mainly on the several species of seals that feed and live among the ice floes.

The seal hunters also forage in a distinctive way: they travel in scattered groups, spyhopping through the loose pack ice, looking for seals. And when they locate a seal on a floe, they have plenty of tricks for taking it off the ice. If the ice is thin, less than a foot or so, they can smash through from below. Sometimes, if a seal is on a small but thick chunk of ice, a large male whale will tilt one end of the floe up with its head, tumbling the hapless seal into the clutches of the rest of the waiting herd. At other times, a group of whales will swim off to 150 feet or so from a target seal, then turn and charge it. At the last second the whales turn sharply, sending a large wave over the floe that washes the seal off the ice and onto the menu. According to one report posted on the Internet, a killer whale lunged completely out of the water, stranding itself on an ice floe as it grabbed a seal. Immediately thereafter, two other herd members clapped their mouths onto either side of its tail and pulled it back into the water. I think people who train killer whales may be giving themselves too much credit.

After three seasons in Antarctica, I am convinced that in addition to the familiar killer whale from around the world, at least one and probably two additional species of killer whale lurk in the icy waters around the cold continent. What I have seen are three quite different-looking forms, which have different, but at times overlapping, ranges and habitats. The three forms also prefer different prey and travel together in herds of different size (the latter behavior suggests their social structure is probably different, too). And though there are no discernible physical barriers to prevent intermingling or interbreeding, I have never seen mixed herds or any individual that looks like an intermediate form, or hybrid. The failure to find any social mixing or apparent hybrids is highly significant in itself.

Pack-ice killer whales living along the Antarctic Peninsula may constitute a second new species. Characterized by large "eye patches," whitish oval markings above and behind the eyes, these orcas prey mainly on seals. The three most prominent spyhopping orcas in the photograph have encircled a Weddell seal on an ice floe; a leopard seal is at left, on an adjacent floe.

Like the earlier reports of the Soviets, these conclusions will be met with healthy skepticism by other marine-mammal scientists. To meet this challenge I have already begun some collaborative studies on the genetics, vocalizations, and morphology of Antarctic killer whales that will bring additional evidence to bear on these issues. The preliminary analysis of the tissue samples I have collected, for instance, already suggests that the three forms may not interbreed, but the results are still preliminary and verification will take a while. There are no simple answers.

But there is a sense of urgency to learn more about the Antarctic pack-ice killer whales, an urgency that goes far beyond academic concerns. Fishing boats from New Zealand and elsewhere have recently begun to experiment with commercial fishing for Antarctic toothfish in the southern Ross Sea. That raises a host of questions for pack-ice killer whales. How dependent are they on toothfish? How abundant is the toothfish? How many whales do the toothfish support, and where else do those whales occur? Will the new fishery, as our work suggests so far, endanger the food source of an entirely new and independent species?

Biologists have a long way to go before they can resolve such questions. Yet the answers could become critically important to the survival of the whales, particularly if they are forced to compete with an industrial-scale fishery. Until now, their obscurity in the Antarctic pack ice has served them well. But it may be time for pack-ice killer whales to come in out of the cold.

Robert L. Pitman is a marine ecologist with the National Marine Fisheries Service in La Jolla, California. He spends six to eight months a year at sea studying whales and dolphins. His most recent contribution to Natural History *was "Alive and Whale," in the September 2002 issue.*

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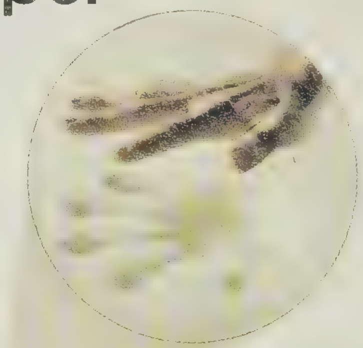

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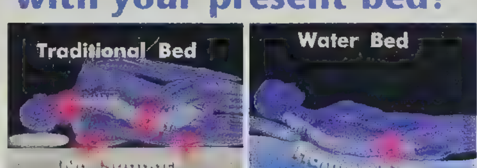

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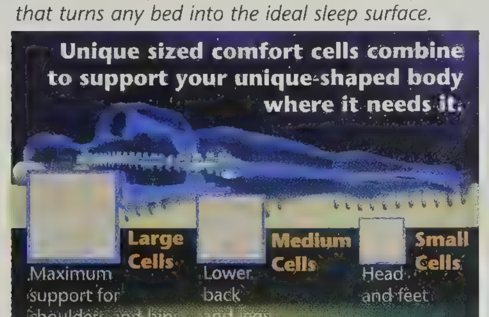

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Uphill Flight

A partridge's ability to climb overhanging slopes might explain how dinosaurs took to the skies.

By Adam Summers ~ Illustration by Roberto Osti

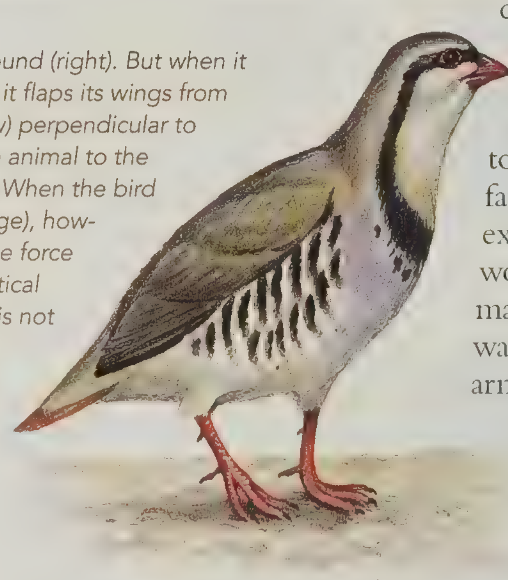
The debate over the origin of birds has raged through the paleontological community for more than a century. Fitting species into evolutionary family trees is painstaking and often contentious work, but truly amazing discoveries of feathered fossils in Liaoning Province in northeastern China have enabled paleontologists to identify the group of dinosaurs that gave rise to Tweety and brethren. The fossils, unearthed in the past decade, even give a peek at the origin of feathers. But paleontologists still debate one point: How did bipedal but terrestrial archosaurs (the "old lizards," which include dinosaurs, birds, and crocodilians) learn to flap their arms and fly? Not surprisingly (given the title of this column), biomechanics has come to the rescue. One of the most compelling hypotheses for the evolution of avian flight has recently been well fortified by observing the habits of some of today's poorest fliers.

Two main camps have dominated the debate about the origin of flight. According to the "trees-down" camp, arboreal dinosaurs first evolved the ability to glide off their perch in a tree, much the way colugos—the so-called "flying lemurs"—and some frogs, lizards, snakes, and squirrels do today. Later, the gliders evolved the ability to flap from tree to tree.

Proponents of the trees-down scenario maintain that wings and feathers would have been useful for gliding, even if they preceded such adaptations as the shoulder girdle, the huge pectoral muscles, and the peculiar wrist and hand structures that make possible the powered, flapping flight of birds. Yet, as detractors of the hypothesis point out, none of the extant gliding animals perform even rudimentary flapping. They are all strictly gliders, and there is no reason to suppose they will ever be otherwise. Even worse, the dinosaurs most closely related to birds, the unfeathered dromaeosaurs, which include such terrors as *Deinonychus* and the better known *Velociraptor,* were clearly terrestrial. So even though a change from gliding to flapping might be an easy idea to swallow, neither the several independently evolved gliders nor the fossil record lend it any support.

Partisans from the second camp, in contrast, favor a "ground-up" hypothesis. In their view, terrestrial, bipedal dinosaurs flapped their "arms" first and later evolved into fliers. But the ground-up hypothesis has faced an even tougher challenge than the trees-down view. Although the fossil record clearly demonstrates that pre-avian dinosaurs were fond of terra firma, explanations that require the transition from bald, sprinting dinosaur to feathered, flapping bird seem a bit far-fetched. Feathers might have, for example, evolved as insulation, which would further imply that dromaeosaurs were endothermic, or warm-blooded. Or maybe feathered arms were useful as a net to catch flying insects, or as a horizontal stabilizer—like a tightrope-walker's pole—for swiftly running, predatory bipeds.

One biologist has come



Chukar partridge does not use its wings when on level ground (right). But when it climbs a steep slope (lower illustration on opposite page), it flaps its wings from roughly its head to its tail, generating a force (purple arrow) perpendicular to the plane in which the wings move. That force "holds" the animal to the ground, giving extra traction to the bird's feet as it climbs. When the bird climbs a vertical surface (upper illustration on opposite page), however, its wings beat in a more back-to-front fashion, and the force they generate has both a horizontal (blue arrow) and a vertical (red arrow) component. Although the vertical component is not necessary for climbing a tree trunk—the bird generates enough force for that with its legs alone—the component shows that the bird (or, equally, perhaps, a protobird or a feathered dinosaur) can redirect the wing-flapping force merely by altering the plane in which the wings are flapped. Such an ability would have been crucial to the origins of flight, as wings were co-opted to provide thrust instead of traction (top).

up with a ground-up proposal that, on the face of it, might seem even more off the wall. Kenneth P. Dial studies the biomechanics of flight at the University of Montana in Missoula. He suggested recently that flight arose from arm movements intended to push a bird (or a feathered dinosaur) into the ground rather than lift it up. The genesis of that odd idea was his observation that, when running up a slope, a chukar partridge *(Alectoris chukar)* flaps its wings quite differently than a bird does when it tries to get off the ground.

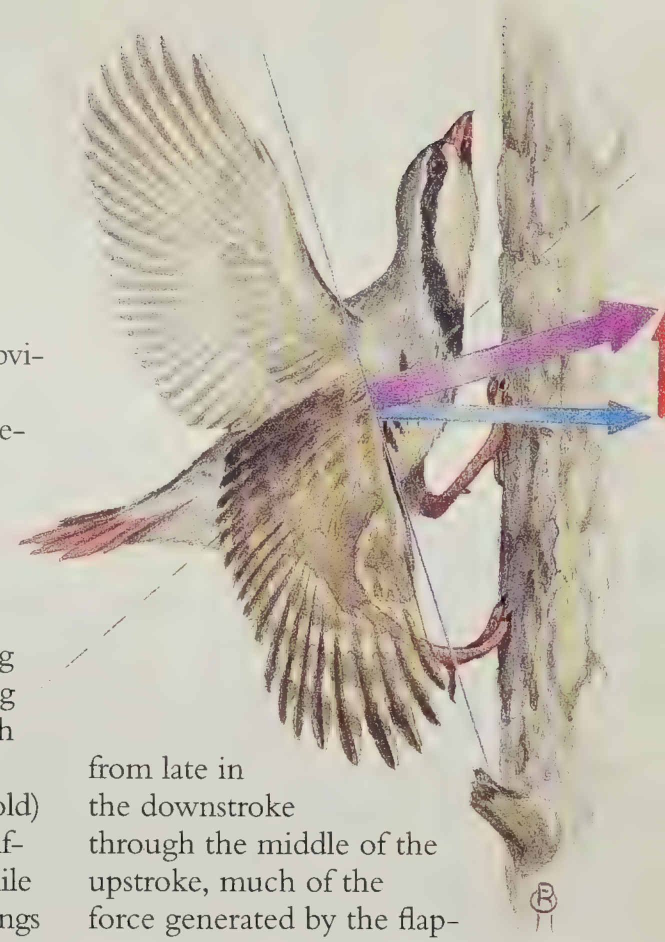
Partridges, chickens, and quail are known as galliform birds (the name comes from the Latin word *gallus,* meaning "rooster," and the Galliformes are all chickenlike). Typically, they have broad, stubby wings; easily fatigued flight muscles; and chicks that are ready to run, though not to fly, when they hatch. When a predator such as a fox or a weasel threatens a young chukar partridge, the bird escapes by fleeing up a steep slope. As it runs uphill, the chukar flaps its wings madly. The behavior has long been regarded as a failed attempt at flying, pointless because the young chukar's flight feathers (called remiges) are not yet fully developed.

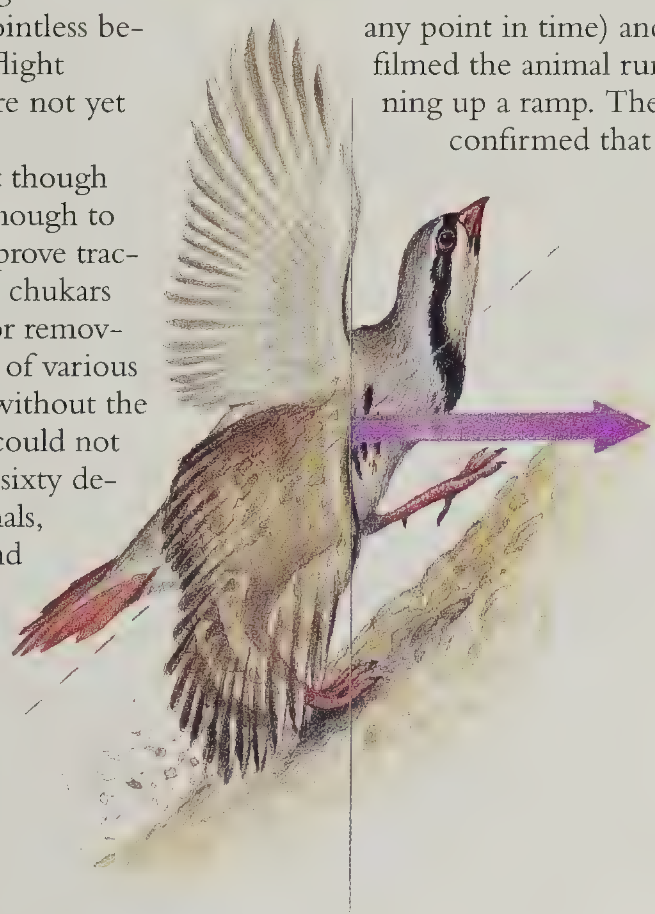
Dial first established that though the remiges are not long enough to enable takeoff, they do improve traction enough for the young chukars to climb. After trimming or removing the remiges of chukars of various ages, Dial discovered that without the help of feathers, the birds could not run up slopes steeper than sixty degrees. Fully feathered animals, however, could scamper and flap their way up vertical and even slightly overhanging slopes.

Dial then turned his attention to the birds' legs. To measure their contribution to the climb, he constructed two kinds of ramp, smooth and textured, which gave quite different traction to scrabbling claws. No matter how well feathered they were, adult birds and young birds alike couldn't scale smooth ramps steeper than fifty degrees.

The data could be explained in two ways. It might initially seem obvious that the flight feathers, though short on the younger birds, nonetheless provide enough vertical lift to make the chicks light on their feet, boosting them up the steeper slopes. Alternatively, the flapping wings could be generating force in the direction of the ramp, increasing the hind-limb traction of the fleeing chicks. This hypothesis also fits with another observation: the stroke of every chukar's (whether young or old) wing beat while running is quite different than that of its wing beat while flying. Rather than flapping the wings from back to belly, as other birds do, the partridges flap from head to tail.

To test the two hypotheses, Dial and his student Matthew W. Bundle attached a small accelerometer to the back of a bird (the instrument measures the acceleration of the bird's center of mass at any point in time) and filmed the animal running up a ramp. They confirmed that





from late in the downstroke through the middle of the upstroke, much of the force generated by the flapping wings helps a chukar's feet get traction.

This research implies a plausible model for the selective advantage of both the flapping motion and a poorly feathered wing. Lightly feathered dromaeosaurs might have relied on wings for help in climbing steep slopes and even entering trees, just as extant galliform birds do. The peculiar flapping style that helps ground the bird could then easily be co-opted into the wing stroke now present in flighted birds. The chukars vary the angle of their wings depending on the slope of the substrate they're climbing, and the angle becomes increasingly similar to that of a flying bird as a chukar climbs slopes of ninety degrees or steeper.

It's not conclusive evidence for the evolution of flight—and since behavior doesn't fossilize, one can never be certain. For the first time, however, the ground-up proponents have a model that's not so much "off the wall" as up it.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine (asummers@uci.edu).

Gusev crater (left), the landing site for the NASA rover Spirit, may be an ancient lake bed. Feeding into the crater from the southeast is Ma'adim Vallis, a dry valley that appears to have been cut by a 540-mile-long river. (Ma'adim is Hebrew for "Mars.") The Gusev crater, some 100 miles across, probably dates to at least 3.8 billion years ago, when the large-scale bombardment of the inner solar system by meteorites ceased. The crater floor, however, is quite smooth, probably because of the deposition of sediments by the river, which could have continued until much later. Eventually rivers would have ceased to flow, probably because the planet turned colder (if, indeed, it was ever warm) and the remaining liquid water either froze or evaporated into space. The photomosaic shown here was made by a Viking orbiter; "north" is toward the left.

What Became of the Water on Mars?

This January, a cluster of spacecraft will converge on the Red Planet, probing for clues to the mysterious but unmistakable role of water in its past.

By Michael H. Carr

As this issue of *Natural History* went to press, at least six spacecraft were already orbiting—or speeding toward a rendezvous with—the planet Mars. In the vanguard of this wave of martian exploration are two NASA orbiters, the *Mars Global Surveyor,* in orbit since 1997, and the *Mars Odyssey,* in orbit since 2001, which have by now collectively observed the planet for eight years. The two have already returned an enormous amount of data about Mars: its topography, which reflects a surprisingly complex geological history, incorporating thick stacks of layered sediments and seemingly recently waterworn gullies; its ancient magnetic field, now vanished because its core has cooled, but still traceable in the magnetization of ancient rocks; its surface chemistry and its primarily basaltic mineralogy; and its fine-scale surface structures, sculpted by wind and ice. The data from the two orbiters have also been crucial for planning the other missions now approaching Mars, particularly in helping planetary geologists pick exploration sites that are both scientifically interesting and relatively free of hazards to landing.

First among the approaching missions is another orbiter, *Nozomi,* launched by Japan's Institute of Space and Aeronautical Science in 1998. It is due to arrive in January. *Nozomi* will examine the interaction of the planet's upper atmosphere with the so-called solar wind, made up of highly energetic particles from the Sun. Since Mars has no magnetic field, it is constantly bombarded by the solar wind. The particles carry enough energy to break molecules in the upper atmosphere into their atomic constituents. Some of the lighter resultant elements get carried away in the solar wind, and so the planet is gradually losing its atmosphere. Knowing how fast that is happening today will enable scientists to estimate how thick the atmosphere was in the past, and so—because of the greenhouse effect of an atmosphere—how warm the planet may once have been.

This past June the European Space Agency launched the *Mars Express,* made up of an orbiter, the eponymous *Mars Express,* and a lander known as the Beagle 2. *Mars Express* will go into orbit this Christmas Day, minutes after Beagle 2 is scheduled to land on Isidis Planitia [*see map on page 35*]. The lander is to measure surface and atmospheric properties, and will probe as deep as five feet into the martian soil. Its onboard instruments will seek bulk organic matter, as well as the isotopic signature of the biologically important element carbon. Most elements occur in nature as a mix of isotopes of slightly differing atomic weights. On Earth, some biological processes preferentially utilize certain isotopes of some elements, so that the carbon isotopes that occur in organic molecules, for instance, have different weights than the ones that occur in inorganic compounds. Measuring the isotopic ra-

Teardrop-shaped islands in the region known as Ares Vallis suggest the awesome force of martian floods. The large crater at the lower right is about three miles across. The islands were left standing as the floodwaters, deflected by craters, eroded away and scoured the surrounding terrain. This region is near the 1997 landing site of the Pathfinder rover. Water would have flowed from the lower right corner of the image in a torrent probably lasting a few days—if earthly floods are any guide. The image was made by the Mars Odyssey.

tios on Mars will provide clues about possible biological activity.

The orbiter *Mars Express* has numerous instruments for analyzing the surface and atmosphere, including a high-resolution stereo camera and instruments for measuring surface composition that complement the ones on *Mars Global Surveyor. Mars Express* also has a radar device for detecting water more than a mile below the surface.

Finally, this past summer NASA launched two Mars rovers, which will join the two U.S. spacecraft already examining the planet. Spirit, the first rover, is scheduled to land on the surface on January 4, 2004; Opportunity, the second, will land on January 25. The two rovers will land on opposite sides of the planet and investigate the geology of regions where liquid water might once have been present. The targets of their searches will be water-bearing minerals and sediments laid down by water.

The two rover missions, along with the other four, constitute by far the greatest assemblage of spacecraft people have ever sent to Mars. Their presence will dramatically pick up the tempo of the research begun by the Viking missions and, more recently, by the 1997 Pathfinder rover. Those missions failed to find any evidence of life on the martian surface. Yet of all the extraterrestrial bodies in the solar system, Mars is still the most likely place where conditions might have been hospitable for life. If Spirit and Opportunity successfully carry out their missions, planetary scientists will have a much better idea of whether some form of life evolved on Mars in the past, and of where we might best go to look for it, or for its remains.

The modern roots of people's fascination with Mars extend at least as deep as the late eighteenth century. By that time observations had already revealed that Mars has some remarkably Earth-like qualities: polar caps, seasons, clouds, a day that lasts roughly twenty-four hours, and even, it seemed, oceans. On the basis of those observations, the contemporary English astronomer William Herschel speculated that life existed on Mars.

It wasn't until the late nineteenth century, however, that the public became caught up in what quickly grew to be a frenzied discussion about the ways of martians. The dynamo behind the popular hysteria was a nineteenth-century American named Percival Lowell. Lowell, a scion of a prominent Boston family, was a devotee of Asian culture and an accomplished amateur astronomer. The main "evidence" Lowell offered for his speculations about life was an elaborate network of "canals" that had been observed and mapped by the Italian astronomer Giovanni Schiaparelli. Lowell suggested that intelligent martians had built the "canals" to transport water from the polar caps to the equatorial deserts. Other observers failed to see the waterworks, but the possibility of civilizations populated by martian little green men led to a torrent of writings about martian invasions, the potential colonization of Mars, and the threat of interplanetary wars.

In spite of Lowell's claim to the contrary, little can be seen of Mars's surface features through a telescope; the planet is just too small and too far away. The sightings of the canals proved to be imaginary, the result of too much striving to make out features at the limits of telescopic resolution. Scientific interpretation of the martian surface did not realistically

begin before observations could be made from spacecraft. And for those hoping to confirm Lowell's ideas, the first such images, obtained in the 1960s by NASA's *Mariner 4,* were deeply disappointing. The small areas photographed showed no canals, no oceans, no oases.

But water on Mars still seemed a real possibility. The *Mariner 9* spacecraft revealed a complex surface geology: volcanoes, canyons, dry valleys, lava plains, and, most intriguingly, flood channels. The discovery of the flood channels led to tantalizing visions of running water—and it went almost without saying that where water flows, there could be life. The data were returned to Earth in 1972, just as NASA was preparing the Viking missions. The discoveries were timely because the main emphasis of those missions was to search for life. Once again, however, the outcome was disappointing: Viking did not even find organic molecules suggestive of the presence of life on the planet's surface—much less life itself.

After the Viking program, the pace of Mars exploration slowed. The focus shifted from the direct and rapid detection of life to acquiring a better understanding of the planet. That still meant looking for water, or at least for where it might have been. In the meantime, public attention drifted elsewhere, until two events renewed wider interest in Mars.

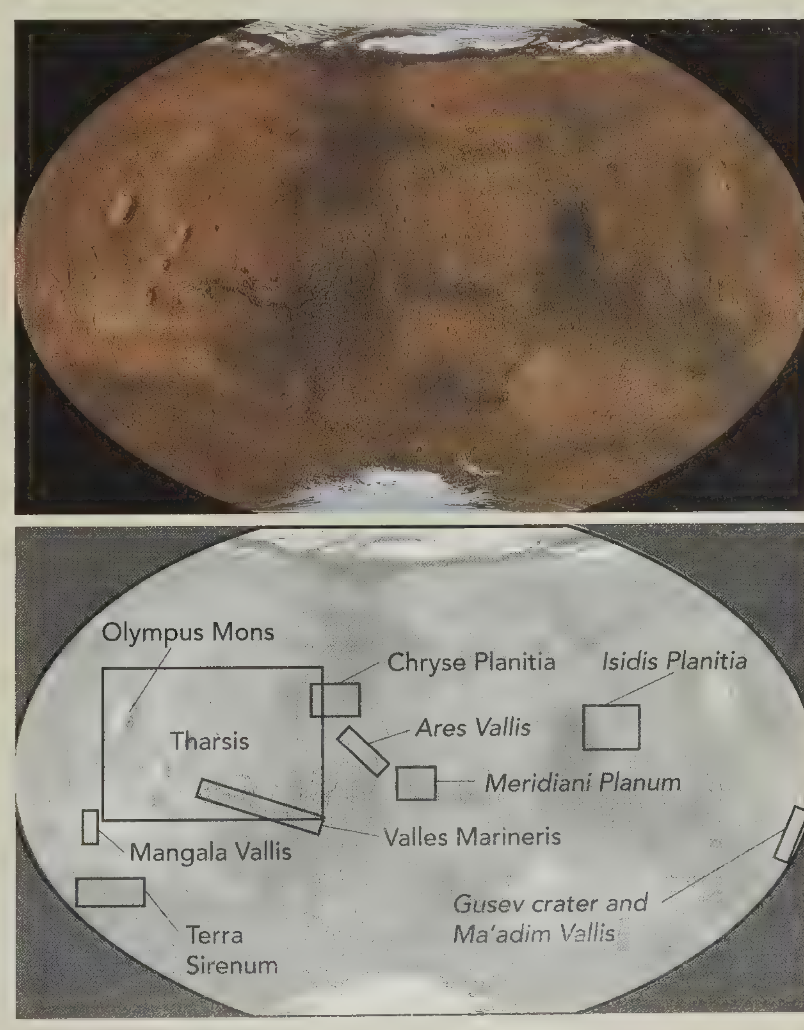
The first event was the announcement in 1996 that a meteorite from Mars contained evidence—possibly fossilized bacteria—suggestive of ancient life. The second event was the extraordinary success of NASA's Pathfinder rover in 1997. The martian meteorite that caused such a fuss in 1996 is generally no longer considered to contain any fossils, and nonbiological explanations of the observed mineral formations now seem more appropriate. Yet the search for water—and life—on Mars has hardly been abandoned. The new convergence of spacecraft is proof enough of that, all of them trying to help answer essentially the same questions that fired the imaginations of Herschel and Lowell: Has liquid water ever been abundant on the martian surface? And if so, has it enabled the planet to support life?

The geology of Mars is a spectacle to behold. The planet's southern hemisphere bears the scarring of heavy bombardment by meteorites; the craters, much like the ones that pockmark the highlands of our Moon, clearly date to the era, sometime before 3.8 billion years ago, when all the bodies of the inner solar system were subject to heavy meteorite bombardment [*see "Moonstruck," by G. Jeffrey Taylor, September 2003*].

The northern martian hemisphere, however, is sparsely cratered, indicating that the old cratered surface there has been buried by younger materials. What are these materials? They could be volcanic, but Timothy J. Parker and his coworkers at NASA's Jet Propulsion Laboratory in Pasadena, California, have speculated that they are sediments in what were once ocean basins. Their elevations are some three miles lower than those of the cratered southern uplands. Perhaps, then, the old, cratered surface is partly buried by marine sediments. But what exactly caused the northern depression is unknown.

Straddling the boundary between the northern plains and the southern highlands is Tharsis, a broad dome more than 3,600 miles across and more than six miles high at its center. The dome is comprised mostly of layers of volcanic rock, which can be seen in the walls of canyons on the dome's eastern flank. On the Tharsis dome are several huge volcanoes, the largest being the 370-mile-wide, fourteen-mile-high Olympus Mons.

But Olympus Mons is not the most spectacular surface feature of the planet. That distinction prob-



Mars can be roughly divided into a low, northern terrain—possibly the basin of an ancient ocean—and a highland, southern terrain, which is deeply cratered. The image was made by the Mars Global Surveyor.

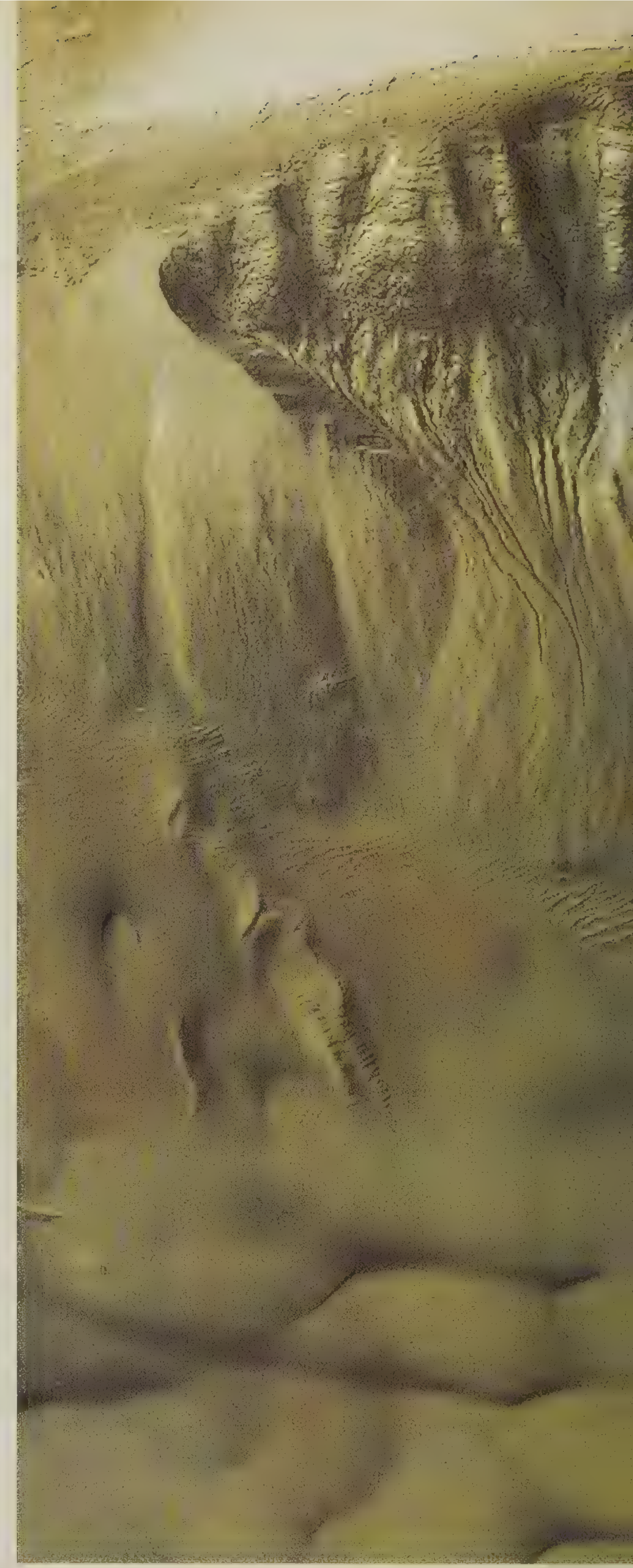
ably belongs to the Valles Marineris, a system of interconnected canyons extending 2,000 miles eastward from the summit of the Tharsis dome to a low region called the Chryse Planitia, which adjoins the northern plains. The canyons in the Valles Marineris are typically 120 miles across and between 3.7 and 6.2 miles deep. Their origin is unknown, but faults that radiate outward from Tharsis can clearly be seen in the canyon walls, suggesting that stresses caused by the Tharsis bulge may have fractured the crust and formed great rift valleys. Once the rift valleys formed, landslides and water erosion probably enlarged the rifts to create the canyons that we see today.

The canyons themselves are not entirely the product of erosion (as is, for instance, the Earth's Grand Canyon). But they still preserve evidence of a wetter Mars. Layered deposits, which may be the remnants of sediments suspended in long-dry lakes, cover some of the floors of the canyons. Near the east end of the system of canyons are some areas of collapsed ground, out of which rise several huge, seemingly waterworn flood channels. Other flood channels emerge from the east end of the canyons as well, possibly as a result of the sudden release of water from lakes within the canyons.

In the effort to explore Mars for water, one of the most perplexing and important issues to address is its climate. Today the planet is inhospitable to any life resembling the life on Earth. The atmosphere, mostly carbon dioxide, is thin: its surface pressure is less than 1 percent that of the Earth's atmosphere.

Such a thin blanket of air provides almost no greenhouse warming, so surface temperatures average −67 degrees Fahrenheit at the equator, and less than −103 degrees Fahrenheit at high latitudes. It is so cold that carbon dioxide condenses out of the atmosphere each winter to form thin but extensive polar caps. Their retreat each summer exposes water-ice caps more than a mile and a half thick. Geologists have known about that abundant ice since 1976, but liquid water must be quite rare.

The scarcity of liquid water on Mars today is not easy to square with the abundant evidence that large volumes of water flowed on the planet in the past. In addition to the channels left by large floods, dry valleys that appear to have been cut by slow-moving water also meander across much of the old cratered terrain in the southern highlands. Dry river valleys also occur occasionally on younger surfaces, particularly on volcanoes. Their presence and their distribution on the surface strongly suggest that warm climatic conditions prevailed at times in the past, particularly early in



Deeply eroded gullies in a crater wall, hundreds of feet high, are visible in the upper half of this image from the Terra Sirenum region. The gullies were probably eroded by water, derived either from springs on the crater wall or from the melting of snow that had accumulated within the crater. In this region, many of the rocks are strongly magnetized, indicating that when they formed, early in the history of Mars, the planet had a strong magnetic field. The image was made by the Mars Global Surveyor.

martian history, when most of the valleys were formed. Perhaps early Mars had a thick atmosphere that was subsequently eroded by large impacts and by the solar wind, or was destroyed by chemical reactions with the surface.

But not everything on Mars conforms with that picture of a warmer, wetter planet in the past. Under warm, wet conditions, rocks weather to produce salts, such as carbonates, and hydrated minerals, such as clays. Those minerals have not been detected by the orbiters. Moreover, computer simulations suggest that the greenhouse effects of a carbon dioxide atmosphere could not have created a wet climate: no matter how thick it was, it could not have trapped enough solar energy to stabilize liquid water.

Yet geomorphologists insist that the evidence on the surface for running water is unequivocal. The salts and clays, they argue, must be hidden from view, and some factor must be missing from the computer simulations. Climatologists are equally adamant that warm conditions were unlikely, particularly in the planet's early history. At that time the Sun's energy output was likely to have been lower. But if Mars was never warm and wet, the prospects that some form of life once flourished there become very dim.

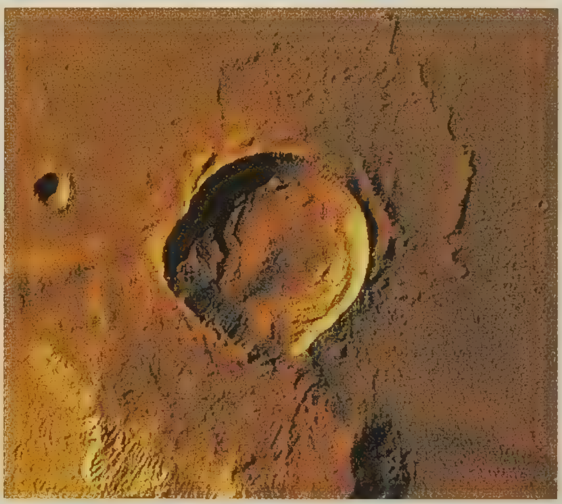
The need to study the history of water on Mars has heavily influenced NASA's choice of landing sites. But mission scientists had to balance that objective with a large number of engineering criteria: a site's altitude must be at least 0.8 miles below the martian "sea level," so that there is enough air for the parachutes to work. The site must be low in latitude as well, so that solar panels can get the most intense sunlight possible. And it must not be too windy, too rocky, too dusty, too rough, or too cold at night.

Two landing sites were eventually chosen. The first, for Spirit, is on the floor of an ancient, ninety-five-mile-wide impact crater called Gusev [*see image on page 32 and 33*]. A broad, 540-mile-long channel known as Ma'adim Vallis cuts through the southern rim of Gusev and extends deep into the southern highlands. Within the crater a group of hills stands at the mouth of the channel, which could be the remnants of a former delta. If the channel was cut by water, the water must have pooled within Gusev before exiting slowly to the north, and much of the material displaced by water erosion would thus have settled out where the water pooled.

Windblown sediments, ash from a large volcano some 150 miles to the north, and lava eruptions within the Gusev crater itself may also have helped fill the crater. Layered deposits have been partly

eroded by the wind in some places, exposing an etched surface. Elsewhere, dunes are common. Sediments deposited by the water may also have been brought to the surface by the meteorite impacts that gave rise to the many craters visible today. If Spirit can find such materials, they would help show whether a lake once existed within the Gusev crater, and under what conditions the sediments were deposited. The size of the particles, their shape, their composition, variations from layer to layer, and the presence or absence of a cement will all provide clues to answer such questions as: What were the climatic conditions when Ma'adim Vallis was cut? What is the composition of the highland rocks? Was the early martian climate ever really warm and wet?

The second landing site, for Opportunity, is in Meridiani Planum, which lies on the side of the planet, opposite the Gusev crater [*see map on page 35*]. The Meridiani site represents a different line of attack in the search for water—a mineralogical rather than a geomorphological approach. Gray hematite, an iron-bearing mineral that normally, but not exclusively, forms in a wet environment, was detected there by the orbiting *Mars Global Surveyor.*



"Splosh" crater, about five miles across, indicates that a meteorite collided with water- or ice-rich ground. Some sixty miles to the west of the crater is a large flood channel (not shown) called Mangala Vallis *(Mangala is Sanskrit for "Mars"). Impact craters such as the one shown are common all over Mars. The image was made by a Viking orbiter.*

The hematite lies in the uppermost layer of a geologically complicated region. That top layer is part of a series of layered deposits partly overlying the ancient cratered surface, which has been cut by river valleys. The hematite layer appears to be thin, and the underlying layers poke through it to the surface in many places. The rover Opportunity should be able to sample both the hematite-bearing layer and the layers below. It may also be able to collect samples of the ancient cratered surface, because meteorite impacts may have excavated such material and thrown it into the site.

How the hematite was deposited presents an intriguing puzzle. It is unlikely that the layers of sediment formed in a lake, because no basin is present. Instead, they were probably deposited from the air, perhaps as volcanic ash. The hematite could have formed from iron-rich materials in the original layers of sediment, or it could have been deposited from iron-rich water percolating through the sediments. The rover Opportunity will seek to determine how the layers were laid down, and look for evidence of water from hot springs, which could arise out of local volcanic warming. On Earth, such springs, as in Yellowstone, commonly support hardy organisms. Perhaps they did on Mars, too.

Operating the rovers on Mars will be a demanding task for those of us who control them from Earth. Every day will begin with an assessment of the data from the preceding day. We'll interpret new images or spectra and determine the new position of the rover as quickly as possible. Then, within two hours of receiving the new data, all the project scientists will meet to discuss the data and what to do next: Shall we do more analyses on the rock we examined yesterday? Shall we get a more detailed look at the cliff a hundred yards away? Shall we move to a new location, and if so, where?

After settling on the broad plan, the various scientific groups—chemists, geologists, mineralogists, and the like—will disperse to draw up a wish list of observations. Two hours later we'll reconvene, reconcile our differences, and make a plan roughly consistent with the resources available: time, power, data bits for transmission, and so forth.

A long and tedious process translates the plan into specific commands that are finally sent to the spacecraft. The rover will carry out the program, and the next day the process will start all over again.

The availability of solar power limits each rover's lifetime to just a few months. The goal is for each to travel at least 600 yards, but the actual distance will depend on the site, the ease of travel on it, and the scientific interest of the terrain around the landing site. At this stage we can only hope we have chosen the sites wisely. But if we have, and if our good fortune continues, in just a few more months some of our questions about Mars's ancient past will be answered, and we will have a better understanding of the role of water in the evolution of the planet. □

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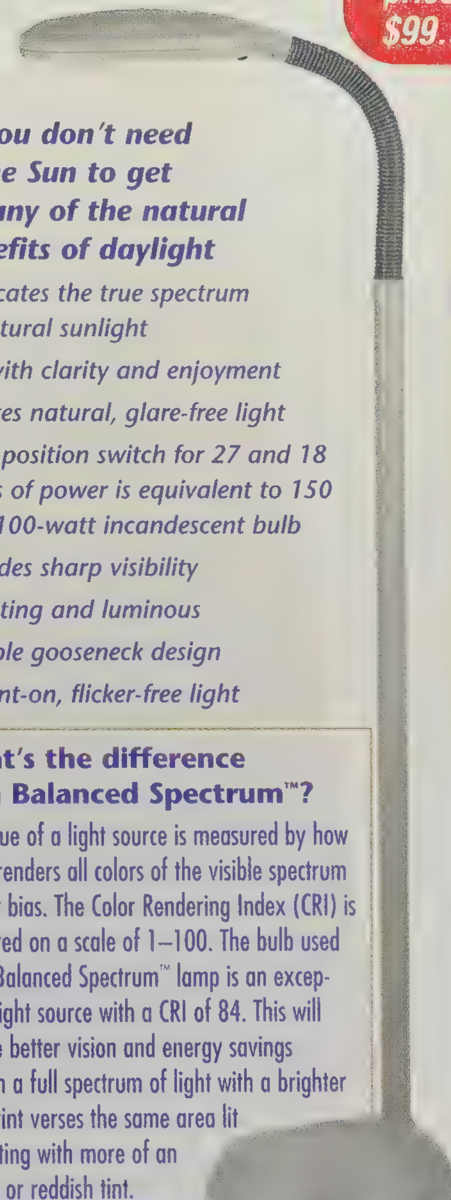

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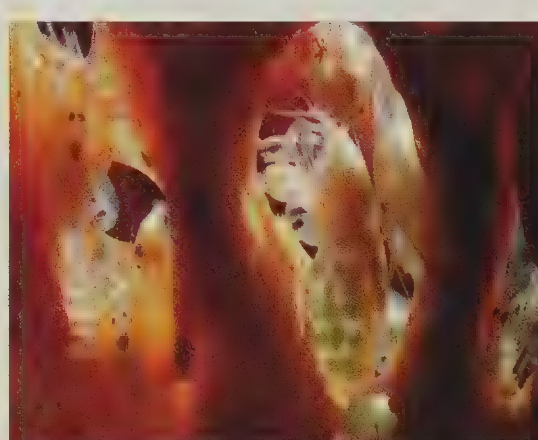
Underwater Urbanites

Sponge-dwelling snapping shrimps are the only known marine animals to live in colonies that resemble the societies of bees and wasps.

By J. Emmett Duffy

Diving the pellucid waters of the Caribbean Sea off the coast of central Belize, down past jewel-like transparent plankton, I see the ridge of the Belize Barrier Reef materializing out of the turquoise depths. Even before the reef becomes visible, I sense its proximity from the muffled crackling that issues from the submarine landscape. In places the crackling is so vigorous it sounds like frying bacon. The noise is the clamor of countless little "snapping shrimps" (also known as "pistol shrimps"), so named for the report each one produces by swiftly closing its disproportionately large and powerful fighting claw. The chorus of snapping and crackling is the sound of homeland defense.



The queen of a colony of Synalpheus regalis snapping shrimps is pictured here inside a living tropical sponge. The green spheres are the queen's eggs.

Although rarely seen, snapping shrimps are one of the great success stories of the Earth's tropical seas. Hundreds of species—all members of the family Alpheidae—and millions of individuals pack into the reef's innumerable nooks and crannies, even lodging in the delicate arms of feather stars [*see photograph on page 43*]. Where snapping shrimps truly flourish, though, is within the internal canals of the living sponges that pepper the reefs. Sponges often exceed even corals in both abundance and species diversity. And throughout the Caribbean, sponge canals—akin to the interior of a Swiss cheese—are teeming with snapping shrimps of the genus *Synalpheus.*

More than a hundred species of synalpheids have been described worldwide, ranging from the size of a rice grain to the size of a baby carrot. Some forty of the species are native to the Caribbean; most of them are ecological specialists that inhabit the passageways of one or, at most, a few sponge species. Their apparently unrequited dependency makes the shrimps parasites: they scrape their sustenance from the linings of their host sponges' canals with a small, specialized claw. (In fact, as the synalpheids live out their lives within a given host, their stomachs become packed with the delicate spicules that form the sponge's skeleton.) Because the inner architecture of their hosts provides not only safe shelter but also a permanent food supply—and because the shrimps are undeterred by the sponges' formidable defensive chemistry, which foils most other predators and invaders—synalpheid populations have expanded to fill nearly every cubic centimeter of the sponge canals.

Having successfully escaped the reef's ubiquitous predators by occupying its living fortresses, sponge-dwelling snapping shrimps face a challenge familiar to crowded urbanites everywhere: stiff competition for space. Several years ago, in an effort to understand why many reef animals adopt symbiotic lifestyles, I conducted a census of Caribbean sponge inhabitants. And I was puzzled, as several workers had been before me, by the paucity of female shrimps. I well remember the night back in 1988 in Panama when, bent over a microscope, I suddenly realized that the shrimp aggregations I was studying were not merely deficient in females. They comprised exactly one breeding female per sponge, even though the aggregations were made up of as many as sixty individuals. That was my first tantaliz-

Elephant ear sponge (Agelas clathrodes), *which occurs throughout the world's tropical oceans, is often inhabited by social species of* Synalpheus *snapping shrimps. As many as 350 individual shrimps, but usually only one "queen," live in such a sponge, much the way social insects live in a hive.*

ing clue that a few species of shrimps are social creatures, living in organized colonies—one colony to a sponge. This way of life—organized, cooperative defense of the community's turf—had previously been unknown among marine animals. Snapping shrimps, it turns out, are living the lives of social insects; they are the ants, bees, termites, and wasps of the deep.

Until quite recently, the retiring lifestyle and puzzling taxonomy of *Synalpheus* made the fascinating biology of snapping shrimps largely inscrutable, despite their abundance. Even my recognition that they live remarkable social lives came about entirely by accident. In retrospect, one can see why evolution might favor such close social relationships. By working together, a group of diminutive shrimps transcends the limitations of size and, with the aid of the single massive fighting claw sported by each individual, musters a formidable resistance against would-be intruders.

A colony of synalpheid snapping shrimps is essentially a two-parent family with a whole lot of grown male children hanging around.

In our next several years of fieldwork my colleagues and I showed that at least five *Synalpheus* species live in tightly packed colonies. Most colonies have just one breeding female each, though in a few colonies we identified more than one. All other members are most likely either males or sexually undifferentiated juveniles. But in *S. regalis*—a species found so far only on the Belize Barrier Reef—the analogy with the social insects is particularly close. A colony always includes just one breeding female and (judging by genetic evidence) one dominant breeding male, even though it can have as many as 350 members. That genetic structure makes most of the members of the colony into full siblings: offspring of a single breeding pair that reigns as "queen" and "king" for most of the colony's life.

Such collections of kinfolk arise because the social species of synalpheid shrimps exhibit "direct development": their eggs hatch directly into crawlers rather than into the planktonic swimmers that typically hatch from the eggs of their close crustacean relatives. Born into a suitable sponge, juvenile synalpheids needn't travel far to fulfill their needs. Both observational and genetic evidence indicates that the juveniles of direct-developing *Synalpheus* species typically remain for an extended time—perhaps for life—in the sponge of their birth. Periodically a few young adult snapping shrimps probably strike out in search of a new domicile, but in general, a colony of *S. regalis* is essentially a two-parent family with a whole lot of grown male children hanging around.

In the parlance of behavioral ecology, the genetic and social properties of *S. regalis* and its direct-developing, colonial cousins make the species "eusocial." The term means that most inhabitants of the colony, rather than engage in reproduction themselves, help raise and defend the offspring of a lucky few.

In spite of the seeming evolutionary advantages of a common defense, eusocial animals present one of the most enduring paradoxes in nature: If adaptive evolution proceeds via the differential survival and reproduction of individuals, how can a species arise in which most individuals never breed at all? Darwin himself was famously troubled by the dilemma; in *Origin of Species* he writes that the phenomenon of sterile workers among the social insects posed the "one special difficulty, which at first appeared to me insuperable, and actually fatal to my whole theory." The extreme case of the sterile worker, however, is just one example of a broader question: How does evolutionary theory account for the occurrence of altruism—behavior that does not benefit an individual creature but is beneficial to others of its species—in a Darwinian world?

Darwin correctly anticipated that the key to the paradox of eusociality is the close genetic relatedness between an insect colony's breeders and its sterile workers. But the full explanation did not emerge until the 1960s, when the late English evolutionary biologist William D. Hamilton first put forward his ingenious ideas. As Hamilton pointed out, among species in the order Hymenoptera, a complex mechanism of sex determination known as haplodiploidy gives rise to "supersisters": all the female offspring of a colony's queen share 75 percent of their genes, rather than the 50 percent shared by full sisters in most other animals. In other words, in colonies of social insects the sterile workers, which are almost exclusively female, are more

closely related to their sisters than they would be to their own offspring (if they had any).

Hamilton suggested that the differential relatedness between sisters and offspring might explain the high frequency of eusociality among hymenopterans. In theory, a female social insect gets a larger genetic payoff from raising a sister than she does from raising a daughter. Hence a worker female is better able to transmit her own genes to future generations indirectly, by ensuring that the queen mother of the colony produces more "supersisters," than she can by breeding herself. The social structure of the colony thus emerges from the genetic self-interest of its constituent workers.

The close genetic relatedness among colony members in *S. regalis* is consistent with the usual pattern of eusociality based on kinship. But genetics is only part of the story. Many animals live in kin groups; few, however, have taken family life to the extremes that the eusocial animals have. Colonies of bees and snapping shrimps have hundreds of members, but the number of breeders in each colony hovers around one. As Hamilton recognized, the other, interlocking part of the story behind what is often called "animal altruism"—the foundation of advanced sociality—is ecology.

In the past couple of decades biologists have documented eusociality in a growing list of animal species besides the social insects. Those species include the naked mole rat, a burrow-dwelling mammal that lives in East Africa; certain aphids; a group of inconspicuous gall-forming insects called thrips [*see "Altruism in the Outback," by Bernard J. Crespi, November 2001*]; an Australian "ambrosia" beetle; and, now, sponge-dwelling snapping shrimps.

As the number of such examples grows, so does the opportunity to identify the evolutionary drivers of advanced social life. A good way to start is to look for commonalties among disparate eusocial animals. In 1991 the evolutionary biologist Richard D. Alexander of the University of Michigan in Ann Arbor and his colleagues compared naked mole rats and termites. Both of these eusocial species are genetically diploid—that is, their offspring carry two sets of chromosomes, one set from each parent. In that regard, they are just like most animals other than the hymenopterans.

Alexander and his coworkers then proposed that most cases of eusociality in diploid animals would arise when three conditions are satisfied: the animal undergoes a gradual metamorphosis sometime during its life cycle; the offspring receive extensive parental care; and the individual animals occupy, in the words of Alexander and his colleagues, "long-lasting, expansible niches (nests or microhabitats) safe from predation and rich with food that does not require exiting the safety of the niche to obtain it." Those three conditions, they contended, promote sustained interaction among close relatives. Furthermore, when the three conditions are satisfied, nonbreeders can increase their genetic contribution to future generations indirectly, either by helping close relatives to breed or by defending the communal nest.

Sponge-dwelling shrimps are also diploid, and so they provide an independent test of the hypothesis put forward by Alexander and his team. And sure enough, the eusocial species of *Synalpheus* are among the few crustaceans that undergo gradual metamor-

Feather star is an echinoderm that serves as home turf for Synalpheus *shrimps in the Indian and western Pacific Oceans. One shrimp, with an oversize left fighting claw, is visible at the two o'clock position.*

phosis (other examples are sow bugs and sand fleas), and among the even fewer in which offspring remain with their parents for a goodly amount of time. Moreover, the quoted passage is an almost perfect description of life within the long-lasting niche of a sponge's canals. The lives of snapping shrimps seem to offer dramatic support for the contention that those three conditions lead to eusociality.

But according to Alexander and his colleagues, there is a fourth condition that strongly drives eusociality: enemy pressure. Here, too, evidence from synalpheids supports their analysis. The occupied territory in an individual sponge is usually filled to capacity. But the canals of a living sponge are too narrow for most predators of the shrimps. What kind of enemy could the shrimps be defending against?

The answer appears to be other synalpheids. The host sponge provides such a scarce and valuable resource—combining abundant food, living space, and safety from predators—that settling and keeping it is a matter of life and death for the sponge dwellers. My associates and I have witnessed defenders among captive colonies in the laboratory fighting to the death to repel intruders—clear evidence of the high stakes of territorial defense [*see photograph above*].

Turf war between two male S. regalis snapping shrimps. Each brandishes his huge fighting claw (leaf-shaped structures in contact at center of photograph) at his opponent prior to physical battle.

In a Darwinian world, nonbreeding members of crowded colonies must be contributing to the colony, or their burden on resources would not be tolerated. Observing captive experimental colonies of *S. regalis,* my team has discovered that large nonbreeding males constitute the first line of defense against intruders. Such males often patrol boldly and restlessly throughout the sponge, and they are more likely than other colonists to be found near its periphery. Like the honeybee workers that sacrifice their own lives to protect the hive, they are the colony's sterile defenders.

Other eusocial animal groups defend themselves with stingers, mandibles, and sharp teeth. Synalpheid shrimps and some of their closest relatives also possess a formidable defensive tool: the major chela, a marvel of bioengineering that is also known as the fighting claw or snapping claw. (The smaller, minor chela is used in feeding.) In both sexes of *Synalpheus* the major chela is the most visually conspicuous feature, though it is proportionally larger in males. One of the two "fingers" of the oversize limb bears a plunger that fits snugly into a socket in the other finger. As the plunger is slammed into the socket, a focused and remarkably strong jet of water is forced out, producing the species' characteristic warning: a bubble that collapses with a loud snap.

Physical confrontations between two competing shrimps generally start with contact by the first pair of antennae, and often escalate to a state of readiness in which the snapping claw is cocked open in a threat display. If a fight breaks out, the claw becomes a weapon, grappling with the opponent's claw or pinching it in a sensitive region, sometimes inflicting serious damage. The major chela is used in other ways as well. Eva Tóth, a postdoctoral investigator in my laboratory, is studying a striking phenomenon we call "mass snapping," which probably serves as a warning to intruders: members of *Synalpheus* colonies snap their claws in unison for a few seconds, producing a startling sound clearly distinguishable from the chaotic background noise of the reef environment.

By shouldering the burden of colony defense, the large *S. regalis* males make it safe for the vulnerable queen to feed and reproduce abundantly, and for the sexually undifferentiated juveniles to feed and grow. Field comparisons among species of *Synalpheus* shrimps suggest that the division of labor translates into greater efficiency and greater competitive success. Eusocial species are much better able to keep other shrimps from entering their host sponge than are their non-eusocial relatives.

The division of labor between reproduction and defense is most clearly manifest in *S. filidigitus,* another, smaller eusocial species that lives on the

Belize Barrier Reef, the largest coral reef in the Northern Hemisphere, is prime territory for living sponges and the colonies of snapping shrimps that reside within the sponges.

Belize Barrier Reef and is the closest relative of *S. regalis.* Queens in *S. filidigitus* colonies frequently lose the snapping claw in adulthood, and so must depend entirely on the other adults of the colony for protection. *S. filidigitus* thus presents a striking parallel with the advanced eusocial insects, whose queens typically become nearly helpless egg-laying machines.

Yet Darwin's conundrum remains: Why does only a single female breed? How can the evolution of sterility be explained?

Of several available hypotheses, the most straightforward is dominance: in several wasp species, as well as in social vertebrates such as wolves, meerkats, and certain birds, the breeder aggressively prevents subordinates from reproducing. In *S. regalis,* however, the queens in the captive colonies we observed showed no evidence of such aggression or behavioral dominance. And since the fighting claw is typically missing in *S. filidigitus* queens, the primary breeder in that species could not dominate her competitors through aggressiveness.

A more likely possibility—supported, for instance, by the case of the Damaraland mole rat of southern Africa—is that sterility results from the avoidance of inbreeding, and is often behavioral rather than physiological. Eusocial shrimp colonies, after all, are made up entirely of close relatives. A nonbreeding shrimp has two options: either bide its time and potentially inherit the nest in the future as a breeder, or risk its life defending the colony as a whole, thus indirectly advancing its own genetic fitness by helping close relatives. But the specialized life history and ecology of sponge-dwelling shrimps foster long-term occupation of specific nest sites by multigenerational family groups. Breeding opportunities turn over slowly, and dynastic lineages persist, headed by one or a few breeders of each sex. So the best strategy for a nonbreeding adult is to aid its siblings and parents by keeping intruders at bay.

How, then, to explain the spotty distribution of eusociality among the numerous species of *Synalpheus*? After all, many of the species have direct development and specialize in one or just a few hosts. All the species, moreover, bear the snapping claw. Perhaps the severity of competition, or the low turnover rate in the housing market, tips a delicate balance toward eusociality in certain species. Whatever the details of the explanation, it seems clear that the enigmatic ecology of sponge-dwelling shrimps must hold the key to understanding how these humble creatures have achieved the highest form of social life in the sea. □

The Breadfruit Trail

The wild ancestors of a staple food illuminate human migrations in the Pacific islands.

By Nyree J.C. Zerega

Many years ago a god named Ku came to Hawai'i and married a mortal woman. Together they had a large family, but Ku never told her he was a god. One year, a terrible famine came to the islands, and Ku's family became weak with hunger. When Ku could no longer bear his family's suffering, he confided to his wife: "If I go on a long journey, I can get food for our children and everyone on the island, but I will never be able to return." At first his wife would not hear of such a thing, but after watching her children slowly starve, she finally relented. The couple walked together into their garden, where Ku kissed his wife good-bye and disappeared into the earth. In her grief Ku's wife waited at the spot where he had disappeared, watering it for several days with her tears. Soon a sprout pushed up from the spot and rapidly grew into a tree. Within just a few days Ku's body had transformed into a large tree trunk, his arms into branches, his blood into a white latex flowing through the tree, and his head into a fruit that provided Ku's family with the food he had promised. The tree, and the food, was the breadfruit.

This legend is just one of many that are told to account for the origins of breadfruit *(Artocarpus altilis)*. It is little wonder that the plant is the stuff of legend, for it has been cultivated as a staple starch crop in the Pacific islands for thousands of years. Biologists, however, are still looking for a more down-to-earth explanation of the plant's origins. The puzzle begins with the fact that many breadfruit trees are seedless and sterile. Sometime in the past, cultivators must have transformed a fertile plant into one that needs human intervention to reproduce itself. But what was the ancestral tree? Breadfruit is scattered across thousands of islands in the Pacific, but no close wild relatives grow throughout much of this range. Thus there is no prime local candidate for botanists to name as breadfruit's ancestor. And if the transformation did not occur throughout the Pacific, it probably occurred in just one place, and the sterile trees must have been spread by human means. But where did these people come from?

Seafaring people reached Australia and New Guinea at least 40,000 years ago and, relaunching from those lands, settled the Solomon Islands by 30,000 years ago. But the broader peopling of Oceania—the middle and southern Pacific islands—did not get underway until about 4,000 years ago. Most scholars attribute the resurgence in settlement to a people they call the Lapita, after an archaeological site in New Caledonia. The main evidence for the patterns of their migrations comes from tracing a characteristic style of pottery, in which geometric and, occasionally, representational designs were stamped into the clay. Linguistic and genetic data generally support the archaeological conclusions.

The Lapita, thought to have come from somewhere in island Southeast Asia, first traveled to the northern coast of New Guinea. They continued their migrations eastward through Melanesia and into the far reaches of eastern Polynesia, making their way to Easter Island by about 1,700 years ago [*see map on pages 48 and 49*]. Micronesia is much more culturally and linguistically heterogeneous than Polynesia, and its island

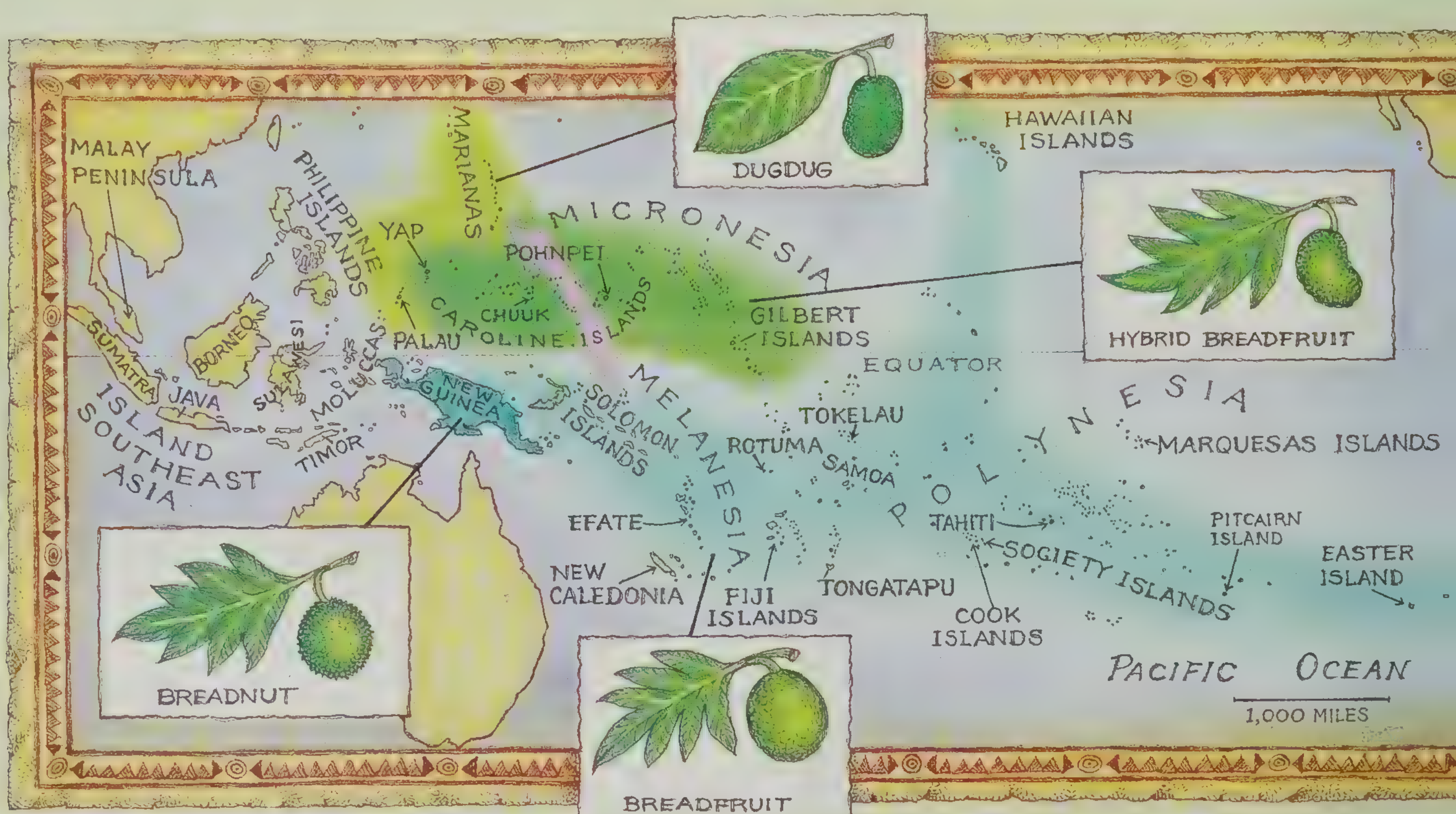
Thomas Gosse, Transplanting of the Bread-Fruit-Trees from Otaheite [Tahiti], *1796. Gosse's hand-colored mezzotint depicts Lieutenant William Bligh, standing at right in uniform, overseeing the collection of young breadfruit trees for transport to the Caribbean. Although the voyage, on HMS* Bounty, *ended in the famed mutiny in 1789, Bligh carried out his mission on a later voyage. Analysis of breadfruit DNA is enabling biologists to trace its wild origins, and the spread of related cultivars by Pacific islanders.*

groups were probably settled by migrants who came at various times from island Southeast Asia, Melanesia, New Guinea, and elsewhere. The last of the principal Oceanic islands to be settled were the Hawaiian Islands, about 1,700 years ago, and New Zealand, about 1,200 years ago—in both cases by Polynesians.

Prehistoric seafarers casting off from their home islands to settle elsewhere would have been sure to take along breadfruit trees, which provide an abundance of fruit. The first breadfruit trees, like their unknown progenitor, may have been capable of reproducing by means of seeds. At some point, however, the voyagers must have begun to transport and transplant root cuttings, which can be nicked with a sharp blade to produce shoots. In that way the trees were propagated vegetatively throughout Oceania.

If migrating people were responsible for the propagation of breadfruit, finding its wild progenitor might contribute to far more than the botanical problem of finding the origins of the plant. By tracing the paths of ancient breadfruit, light might be shed on the routes taken by the ancient mariners who transported it. Unfortunately, reconstructing the plant's botanical history has long proved difficult. During the millennia breadfruit has been cultivated, the trees changed with time and place. Mutations occurred, and cultivators on various islands selected for trees that grew best under local particularly conditions or whose fruits were particularly appealing in size, taste, and texture. My hope was that DNA evidence obtained through the new tools of molecular biology would finally resolve the puzzle of the species' origins.

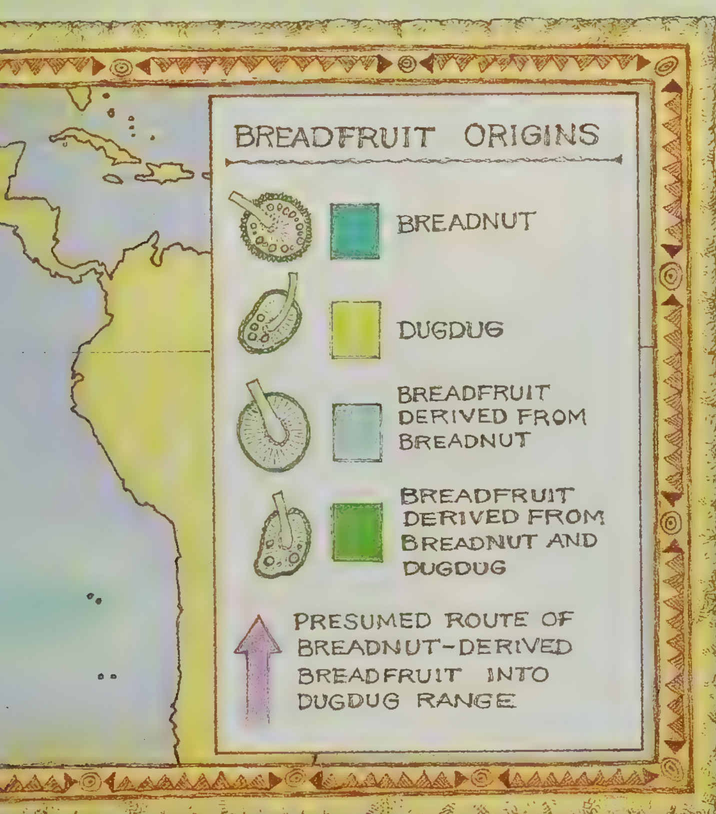
Scholars have put forward at least two testable hypotheses about the origins of breadfruit. The first was advanced in 1940, when Eduardo Quisumbing, a Filipino botanist, suggested breadfruit may be "derived, by selection, from some species perhaps even approximating the 'camansi.'" He was referring to the breadnut, *A. camansi*, native to New Guinea and possibly the Philippines and the Moluccas. It produces edible, chestnutlike seeds. A second, much more complex hypothesis was proposed in 1960 by Francis Raymond Fosberg, an accomplished American botanist of the Pacific flora.



Origins of breadfruit and its precursors, proposed by the author on the basis of her genetic analyses and the archaeological record, are traced through the islands of the Pacific. A seafaring people known as the Lapita quickly spread through Melanesia and Polynesia, bringing the breadnut plant with them as they fanned outward from New Guinea. The Lapita often carried cuttings on their long ocean voyages, and so, over time, the breadnut, propagated by seeds, was transformed into the breadfruit, a plant that is often sterile. At some stage, they or other early voyagers brought breadfruit into the range of the dugdug plant (purple arrow), and so the two closely related species were able to hybridize. Many breadfruit cultivars in Micronesia bear the genetic stamp of that union.

Fosberg implicated two other species in addition to the breadnut. One is the Philippine endemic commonly known as antipolo *(A. blancoi)*, which is used primarily for lumber. The other, often called dugdug *(A. mariannensis)*, is endemic to certain uplifted limestone islands in Micronesia, namely Palau and the Marianas. The islanders consume both its seeds and the surrounding flesh.

Fosberg suggested that antipolo first hybridized with breadnut, giving rise to sterile breadfruit. But he also noted that Micronesian breadfruit has its own unique characteristics. For example, some specimens have leaves like those of the dugdug but seedless fruit like that of breadfruit; others have deeply cut leaves like the breadfruit's, but those leaves have brownish and reddish hairs on the leaf



veins, like the dugdug's. To account for those features, Fosberg suggested that in Micronesia the sterile breadfruit trees had somehow hybridized with dugdug.

To begin my own study into the origins of breadfruit, I wanted to test both these hypotheses about its wild progenitors. That led immediately to my first question: Are breadnut, dugdug, and antipolo the species most closely related to breadfruit, and if not, what is? Second, is there evidence that any of those species contributed to breadfruit's gene pool?

I determined the DNA sequences for two regions of the genome in nearly forty species in the breadfruit genus, *Artocarpus*. The genus belongs to the mulberry family (Moraceae) and encompasses many useful and curious species. On the basis of the DNA sequences, I constructed a family tree for *Artocarpus*, which showed that breadfruit is closely related to breadnut and dugdug but not to antipolo.

In DNA sequencing, the base pairs, or molecular building blocks, in a species' chromosomes are identified one by one. But a single genome can include billions of base pairs. Although the speed at which this kind of data can be generated is rapidly increasing, many biologists must content themselves with sequencing only small regions of an organism's genome. Unless those regions happen to be highly variable, they may not shed much light on the genetic relatedness among closely related species. The regions I had sequenced were just too similar to reveal how breadfruit, breadnut, and dugdug fit together on the tree of life. I needed more data.

I turned to a method of DNA fingerprinting called amplified fragment length polymorphisms (AFLP). In effect, the technique takes many snapshots of an organism's entire genome, increasing the chances that informative regions will be found. The first step in the process is to extract DNA and treat it with enzymes that slice it into many small fragments. Examining all of these fragments is not feasible, so the next step is to "amplify" (make many copies of) only a subset of the fragments. Among the amplified fragments, some will be unique to the single individual source of the DNA, whereas others will be shared with other members of the same species. Of the latter, some will prove to be unique to the species as a whole, and others will be shared with members of various other species. By sorting through the amplified fragments, the investigator can determined which of them are "fingerprints" of particular individuals, species, or even more distant genetic relations.

I realized I would have to analyze tissue from several individual specimens of breadfruit, dugdug, and breadnut. Would that force me to island-hop around the Pacific, collecting samples of trees from tropical forests and white-sand beaches? As arduous (and appealing) as that might be, there was a quicker (and cheaper) way.

Kahanu Garden, part of the National Tropical Botanical Garden, is situated on the Hawaiian island of Maui, near the Pi'ilanihale Heiau, a structure of lava rock thought to be the largest ancient Polynesian place of worship. Approximately ten acres of the garden is devoted to the largest known collection of breadfruit cultivars in the world: more than 200 trees have been collected from

seventeen Pacific island groups and beyond. Although the collection was originally established in the 1970s, the bulk of it was assembled in the 1980s by Diane Ragone, the director of the National Tropical Garden's Breadfruit Institute. At this one location I obtained samples of breadfruit from Java and the Philippine Islands, in island Southeast Asia, and from various islands in Melanesia, Micronesia, and Polynesia. Only a handful of dugdug and breadnut trees grow at Kahanu, however, so I traveled, along with Timothy J. Motley of the New York Botanical Garden, to New Guinea and the Marianas. In both places knowledgeable local botanists helped me collect more samples.

When I examined the DNA from all the trees, I found many genetic fingerprints that were common to breadfruit, breadnut, and dugdug. That confirmed just how closely related the three species are. But I was also able to identify some dugdug fingerprints absent in all breadnut trees, and some breadnut fingerprints absent in all dugdug trees. Looking at the distribution revealed an intriguing pattern. Both breadnut and dugdug fingerprints were present in virtually all Micronesian breadfruit cultivars. But most of the breadfruit cultivars in Melanesia and Polynesia included only the fingerprints of breadnut, not of dugdug.

To some extent, then, both Quisumbing and Fosberg were correct. Overwhelmingly, in Melanesia and Polynesia, breadfruit cultivars were derived through selection from breadnut, just as Quisumbing surmised. But Fosberg was right to think there was something different about the Micronesian breadfruit trees. In Micronesia, breadnut or breadnut-derived breadfruit appears to have hybridized with dugdug, probably not in a single event but in a process known as introgression, in which a series of interspecies crosses are followed by repeated backcrosses. The result was a unique diversity of cultivars.

How do these findings tie in with the migrations of people across the Pacific? Here's a possible explanation. As the Lapita people voyaged eastward from New Guinea, they likely carried along whatever they needed of the wild breadnut, so that they could establish breadnut as a crop. But breadnut seeds remain viable for just a few weeks; seafarers who anticipated a long ocean voyage, such as the ones that led colonizers to regions east of the Solomon Islands, would have known to bring along root cuttings. (In fact, the Lapita vegetatively propagated several of their important crops, including yams and taro.) By propagating and spreading their breadnut trees via cuttings, generation upon generation of islanders transformed it into the breadfruit, a species that did not reliably produce viable or edible seeds but that could be consumed as a starch crop.

Human settlement of Micronesia was not so straightforward as it was in Melanesia and Polynesia, and several migration routes may have been established. One route scholars have suggested began in the eastern Solomon Islands or in the islands to their southeast, and followed a northward course to the Caroline Islands. Lapita or other people taking that route could have introduced the breadnut-derived breadfruit into Micronesia. Migrations and trade routes within Micronesia could then have brought the introduced breadfruit into the range of the native dugdug, where the two species could have cross-pollinated.

Breadfruit tree, shown here in an engraving made about 1800, grows to a height of sixty-five feet.

The earliest breadnut-derived breadfruit occurs in Melanesia, where breadfruit cultivars that produce seeds are still commonly found. I speculate that such fertile plants may be what hybridized with dugdug. Nothing like them persists in Micronesia, however, though the hybrid breadfruit trees themselves sometimes do produce seeds. The ancestral cultivars may have disappeared from the region because of a difference in environmental conditions or because people who lived there—perhaps owing to the availability of the edible dugdug seeds—preferentially selected seedless cultivars.

Finally, the route from Melanesia into Micronesia might well have been a two-way street. I discovered dugdug fingerprints in a small number of

Tahitian breadfruit is shown here as it was published in the journals of Captain James Cook, during Cook's first Pacific voyage, 1768–1771.

cultivars I sampled from the Solomon Islands and farther east, in Efate, the Fiji Islands, Samoa, and the Society Islands. The evidence suggests that hybrid breadfruit cultivars, developed in Micronesia, could later have joined the breadnut-derived breadfruit in Melanesia and Polynesia.

Much more remains to be learned about the finer details of how people selected and spread breadfruit trees. Because of the genetic scrambling that has taken place, and can still occur, between fertile plants, and because of the continual movement of humans, the picture is complex. Bringing it into sharper focus will keep us breadfruit botanists plying the Pacific for years to come. □

Giving Cranes a Lift

A Mississippi refuge preserves a bird and its habitat.

By Robert H. Mohlenbrock

Mississippi sandhill cranes, an endangered subspecies

With their stately stature, wingspreads as broad as eight feet, loud calls, and elaborate courtship dances, cranes are among the most impressive birds in the world. Two species are native to North America, the whooping crane *(Grus americana)* and the sandhill crane *(G. canadensis)*. Whooping cranes, whose population fell to just sixteen birds in 1941, now number about 300, thanks to a much publicized conservation effort. Nevertheless, they still teeter on the edge of extinction. Sandhill cranes, which number more than half a million, would seem to be in much better shape. Yet there are six subspecies of sandhill crane, and not all are thriving. The rarest, the Mississippi sandhill crane *(G. canadensis pulla)*, is the focus of another concerted conservation effort, now under way at the Mississippi Sandhill Crane Wildlife Refuge northeast of Biloxi, Mississippi.

Because this subspecies is listed as endangered, only a limited area of the refuge is open to the public. The best opportunities to view the cranes come in January and February, when the refuge offers tours to blinds overlooking areas where the birds feed. The visitor can always see native shrubs and trees along the entrance road, or follow the Dees Nature Trail that leads through a savanna and along an open water marsh. In addition, Scott Hereford, the lead biologist at the refuge, and his colleagues have created an informative video about the history of the cranes and their environment, which plays at the Visitor Center. The following account is based on information provided by Hereford and the refuge staff.

At one time Mississippi sandhill cranes probably frequented marshes and savannas all the way from southern Louisiana to the Florida panhandle. A savanna is a grassland scattered with trees, a combination that often suggests a manicured parkland. But the savannas along the coast of the Gulf of Mexico were hardly parks; rather, they owed their existence to acidic, poorly drained soils and frequent natural fires, which suppressed shrubs and most trees except for longleaf pines. Because the grasses attracted game animals and were suitable for cattle grazing, Native Americans and early settlers kept the savannas intact by setting fires themselves.

Around the middle of the twentieth century, however, lumber companies systematically harvested longleaf pines from the savannas and planted slash pines to supply the paper industry. The companies suppressed fire and improved the drainage, to favor the growth of the slash pines. Other industries, joined by vacationers and retirees, swelled the surrounding towns and further impinged on the savanna habitat. By 1972, when they were designated a separate subspecies, Mississippi sandhill cranes had been reduced to a single, isolated, non-migrating population near Biloxi that numbered only about thirty birds, including just five or six nesting pairs. Fortunately they soon became beneficiaries of the Federal Endangered Species Act of 1973.

It was a close call: Interstate Highway 10 was slated to pass through the only remaining habitat for the birds. Construction was held up while a federal court case was heard, the first under the 1973 law. As part of the settlement, the Department of Transportation purchased 1,960 acres adjacent to one of the interchanges and along the connecting road to protect some lands from development. Although the

highway was built, this acreage became part of the refuge when it was established in 1975.

The refuge, which covers some thirty square miles, is the object of a long-term restoration project. Through prescribed burning, fire is once again suppressing the growth of invasive shrubs. In areas too wet for fire to be effective, unwanted shrubs and trees are cleared by hand or by machine. Several ponds have also been created for the cranes to roost near, replacing some of the many marshes that were drained years ago.

Mississippi sandhill cranes make their nests on the ground, primarily in the savannas, on the borders of narrow swamps, and on the edges of small ponds. The cranes, which usually mate for life, become sexually mature at about age three, but they often do not become parents until two or three years later. Both parents share in building the nests, incubating the eggs, and caring for the chicks. During the nesting season, in spring and early summer, the female usually lays just two eggs, which hatch in thirty days. The chicks can swim the same day they hatch. Two days later the chicks can accompany their parents into the savanna, and by the time the young birds, called colts, are between seventy-five and ninety days old, they have learned to fly. Unlike many birds, the young cranes remain with their parents until the next nesting season.

Parent birds rarely succeed in rearing both of their chicks. Consequently, since 1965, some of the "extra" eggs have been taken to out-of-state wildlife centers to be hatched in captivity. Some of these birds and their offspring are maintained in captive flocks; others are released. Precautions are taken to make sure that the ones to be released remain wary of people. Some are reared in pens by captive foster parents. Others are hand-reared, but human contact is minimized through the use of one-way glass and full-body bird disguises. Tame young birds are kept in adjacent pens, so that the hand-reared birds will be familiar with other members of their species.

The juvenile captive birds bound for release are shipped to Mississippi after about a month, and they quickly learn to fit in with the refuge population. Now about a hundred Mississippi sandhill cranes live in the refuge or on adjacent land, including about twenty-five breeding pairs—though without the captive-breeding program, the population still could not sustain itself.

Yellow pitcher plants in bloom

HABITATS

Savanna Principal grasses that grow beneath the longleaf pine are Beyrich threeawn, bushy bluestem, cutover muhly, little bluestem, and toothache grass. Colorful spring wildflowers include candyroot, several meadow beauties, Osceola's plume, pale grasspink, rose pogonia orchid, southern colicroot, tuberous grasspink, yellow colicroot, and yellow milkwort. Showing off in autumn are blazing star, bristleleaf chaffhead, goldcrest, redroot, two kinds of native sunflower, woolly sunbonnets, and several species of yellow-eyed grasses.

For visitor information, contact:
Mississippi Sandhill Crane
National Wildlife Refuge
7200 Crane Lane
Gautier, MS 39553
228-497-6322
http://mississippisandhillcrane.fws.gov

Wet depressions in the savannas are home to various sedges and rushes and a few small trees of poison sumac. Because the soil is acidic and infertile, some plants are carnivorous, supplementing their diets by trapping small insects. Among them are a bladderwort, a butterwort, two kinds of pitcher plant, and three kinds of sundew.

Open marsh Sandweed grows extensively beneath bald cypress, pond cypress, swamp bay, swamp tupelo, and other trees. Nonwoody plants in or near the water include arrow arum, bulltongue arrowhead, foxtail club moss, golden club, Jamaica swamp saw grass, pipewort, royal fern, tall pinebarren milkwort, and several kinds of sedges and rushes.

Shrub border Among the native shrubs along the entrance road are black titi, five kinds of holly (dahoon, gallberry, large gallberry, myrtle-leaved holly, and yaupon), leatherwood, two kinds of wax myrtle, two kinds of wild blueberry, and a wild huckleberry.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

Gifted in Science

For the young readers in your life

By Diana Lutz

For Small People

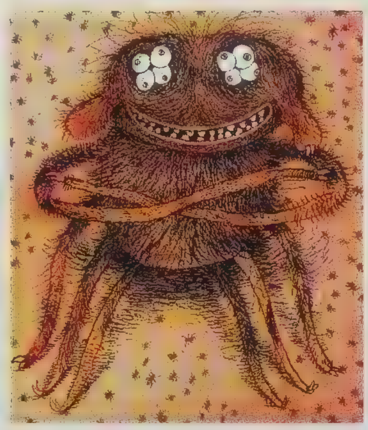
Fireflies at Midnight, *by Marilyn Singer; illustrated by Ken Robbins (Atheneum Books for Young Readers, April 2003; $16.95)*

Fireflies at Midnight describes the everyday lives of common animals on a summer's day. The day begins with a robin's wake-up call and ends with a mole's droning lullaby. On each two-page spread a short poem faces a photograph of an animal that has been

manipulated to look like a painting. Parents will enjoy reading the verses, which expertly mimic an animal's song or the rhythm of its motion, from the frog's "baron I'm the baron" to the firefly's "Come/(flash)/Choose me (flash flash)."

An Interview with Harry the Tarantula, *by Leigh Ann Tyson; illustrated by Henrik Drescher (National Geographic, September 2003; $15.95)*

Radio host Katy Did interviews Harry Spyder about his recent traumatic encounter with a human. As is the annoying habit of interviewers everywhere, she delves into Harry's love life (he must transfer his web sack of sperm to a female, but he's afraid of female spiders because they eat males). Two scientists served as expert consultants for this simple but pleasing narrative, which ends with "Tarantula



Facts." The real draw, though, is Henrik Drescher, whose off-the-wall illustrations make the tarantula a lovable (though admittedly "harry") old crank.

The Queen's Progress: An Elizabethan Alphabet, *by Celeste Davidson Mannis; illustrated by Bagram Ibatoulline (Viking, May 2003; $16.99)*

Celeste Mannis unabashedly admits that *The Queen's Progress,* an ABC book, began life as a long historical novel. But when she finally threw out her thousand-page manuscript and

started over, she had seven years of research at her disposal. They weren't wasted. *The Queen's Progress* is not just an alphabet book; it's also a brief history of a "progress" (the royal version of a summer trip), a murder (or near-murder) mystery, and a seek-and-find book (the queen's three small rescuers appear in many of the illustrations). Because of its complex layering, the book will stand up to many readings. Bagram Ibatoulline's illustrations are done in the style of Elizabethan state portraits; the courtiers' elaborately decorated clothing is rendered more realistically than their faces.

For Medium-Size People

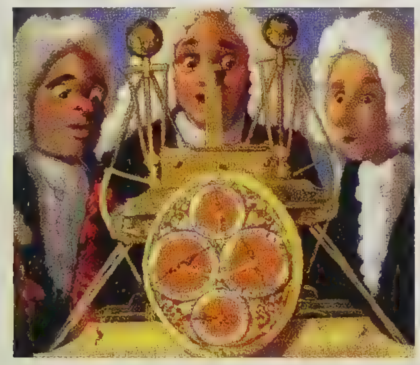
The Man Who Made Time Travel, *by Kathryn Lasky; illustrated by Kevin Hawkes (Farrar, Straus & Giroux, April 2003; $17.00)*

John Harrison, an uneducated but persevering clock maker, devoted a lifetime to inventing a mechanism that would keep accurate time at sea. He thus solved "the longitude problem," making it possible for sailors to avoid shipwreck by determining their east-west position when they were out of sight of land. Since the 1995 publication of *Longitude,* Dava Sobel's best-selling book on the topic for adults, the story of Harrison and his clock has slowly worked its way to more and more elementary reading levels.

Here Harrison appears once again (somewhat improbably) in a superb picture book by an award-winning author and an equally accomplished artist. The continually varying integration of text and art in *The Man Who Made Time Travel* is a book-lover's delight, and its luminous and whimsical

paintings portray even wizened government officials and the mechanical innards of clocks in a warm and friendly glow. This is another Kathryn Lasky and Kevin Hawkes collaboration; their first, *The Librarian Who Measured the Earth* (1994), was selected by the *School Library Journal* as a "best book" of the year, and this one deserves similar accolades.

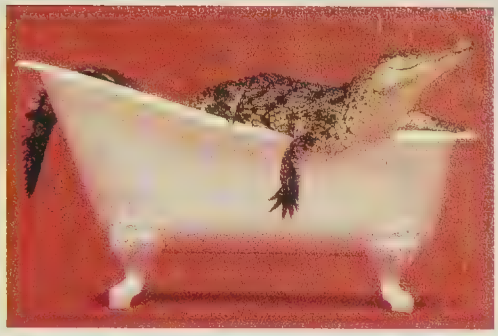
Parents of older children might want to consider *The Longitude Prize,* a book for young adults by Joan Dash, pub-



lished in 2000 (Farrar, Straus & Giroux). It supplies more of the historical context for the longitude problem, and explains how historians know what is known about Harrison. The book is embellished with witty line drawings and cleverly decorated initial capitals, both by Dušan Petričić.

How to Hold a Crocodile: Plus Hundreds of Other Practical Tips, Fascinating Facts and Wicked Wisdom, *by The Diagram Group (Firefly Books, September 2003; $19.95)*

Children of a certain age spend enormous amounts of time trying to figure out what adults are up to by reading *Ripley's Believe It or Not!, The Big Book of Big Secrets, Life's Imponderables,* and other outlandish guides to adult life, apparently under the illusion that they are getting the inside scoop. *How to Hold a Crocodile,* a similar compendium of popular lore, is full of oddball practical tips (how to paint a room, how to cheat at growing a big squash); dubious historical information (how to be a butler, how to make a quill pen); outdated social etiquette (how to choose the appropriate glass, how to get an audience with the



pope); and tricks of various kinds (how to magnetize a walnut, how to climb through a playing card). All this esoterica is punctuated by full-size game boards for obscure games and instructions for playing them.

The editors remark that they were not able to test all of the ideas since "none of [us] was prepared to volunteer for mummification." Accordingly, they don't promise that all the ideas really work. They doubt, for instance, that Aristotle ever managed to measure a flea's leaps by dipping its legs in wax. I can vouch, however, for the method of cleaning a burned pot (fill with cold water, add one tablespoon of vinegar, and boil for five minutes). I tested it several times in the course of writing these reviews.

Horseshoe Crabs and Shorebirds: The Story of a Food Web, *by Victoria Crenson; illustrated by Annie Cannon (Marshall Cavendish Corp., October 2003; $16.95)*

The horseshoe crab is the most child-friendly of animals: slow enough to be caught, about the right size and weight to be carried, fierce-looking but harmless, spectacularly alien, and (if dead) the possessor of a truly magnificent reek. But this gentle book coaxes children to think beyond the beast itself. Every spring, the crabs' mass beaching and egg laying become a great egg feast for starving shorebirds on the wing northward, from Patagonia and Tierra del Fuego. The names of the feeding migrators—red knots and ruddy turnstones—trip off the tongue in lyrical sentences crafted for their sound as well as their

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[illegible]. Annie Cannon's watercol[illegible] the laughing gulls surrounding the text in sinuous S-shaped curves, for instance—similarly combine accuracy with poetry. Victoria Crenson confines to an author's note the gloomy observation that fewer and fewer crabs are returning to spawn, thus freeing children to revel in the joy of the horseshoe crabs' spectacular spring celebration.

For Nearly Grown People

Close to Shore: The Terrifying Shark Attacks of 1916, *by Michael Capuzzo (Crown Publishing Group, April 2003; $16.95)*

An adaptation of Michael Capuzzo's 2001 adult nonfiction best seller, *Close to Shore* tells the true story of the rogue shark that killed three men and a boy along the Atlantic coast early in the twentieth century. It also breaks most of the rules of nature writing. The shark is not a magnificent apex predator, but a kind of ichthyologic serial killer. Transgressing the ideal of objectivity, Capuzzo imagines the state of mind of the swimmers and, even more daringly, that of the shark. He even writes in an ornate style similar to that of contemporary newspaper accounts.

But though he's dancing on a high wire, Capuzzo never falls off. He did the hard work needed to re-create not just the events but also the texture of the time. He read medical and scientific journals, novels, plays, and love poems from the era, in addition to hundreds of newspaper accounts of the events and several hundred books about sharks. More important, he has the storyteller's gift. *Close to Shore* starts slowly, but it becomes a driving and nearly unstoppable freight train of a tale.

The Case of the Monkeys That Fell from the Trees: And Other Mysteries in Tropical Nature, *by Susan E. Quinlan (Boyds Mills Press, March 2003; $15.95)*

Twelve ecological mysteries are set in tropical forests. In each case a scientist notices something odd, follows the clues, tests a hypothesis through experiment, and eventually uncovers a surprising hidden connection or an unsuspected association. One scientist, for instance, wonders why female ithomiine butterflies are following swarms of army ants. After several false leads, he discovers that butterflies are using the ants to locate birds. Why? The bird droppings are a good source of the nitrogen that the butterflies need to produce eggs.

Much ecology writing for children is dull, second-hand, and sermonizing. Susan Quinlan, a biologist herself, reads the primary literature and talks to the scientists whose work she describes. She is among a handful of

children's writers who manage to capture the passion, beauty, and joy of the scientific pursuit. Quinlan's books are also characterized by her unusual respect for a young audience. She is careful to be clear, but at the same time she assumes children can follow the scientists' arguments, that they will be interested, not bored, and that they will value nature as much as she clearly does. Above all, she does not lecture or seek to place on small shoulders the burden of solving the crushing environmental problems our generation has created.

An American Plague: The True and Terrifying Story of the Yellow Fever Epidemic of 1793, *by Jim Murphy (Clarion Books, June 2003; $17.00)*

Children's books about the history of medicine tend to be guilty of old-fashioned scientific triumphalism. But the usual yellow-fever stories, the ones about Walter Reed and about the Panama Canal, are only a small part of the last chapter of *An American Plague.* Written from a disabused modern perspective, *American Plague* points out that reservoirs of yellow fever remain intact in monkeys (thus making its elimination unlikely); that there is still no cure for the disease once it is contracted; and that stocks of the vaccine are limited.

But Jim Murphy's powerful account is primarily a social history. No one knew at the time how yellow fever was transmitted or how it might be controlled, and those uncertainties exposed the fault lines of eighteenth-century Philadelphia society. Murphy discusses the role of black societies in nursing the sick; the famous case of Dr. Rush, who believed so blindly in his own cure (bleeding) that he almost killed himself with it; the improbable heroism of "a grogshop man" named Israel Israel; and even the impact of yellow fever on foreign policy: George Washington had trouble making decisions because his papers had been left behind in "boarded-up houses" when he fled the stricken town.

Those planning gifts for almost-grown-up readers should also consider The Longitude Prize, *noted in the review of* The Man Who Made Time Travel, *above.*

For Grown People with Childlike Curiosity

The Tree of Life: Charles Darwin, by Peter Sís (Farrar, Straus & Giroux, October 2003; $18.00)

Starry Messenger, Peter Sís's earlier book about Galileo, had a bold and simple story to tell, and a clear structure: the Inquisition quenched the stars in Galileo's eyes but could not put out the ones in his mind. *The Tree of Life,* Sís's story of Darwin, is more muffled and difficult—as was the man himself. After a youth spent under his father's thumb, Darwin escaped on the HMS *Beagle,* but on returning to England he fell into procrastination and ill health. He was only stirred to publish

his famous theory years later, when another naturalist was about to beat him to the punch.

Both Sís's books are layered mysteries, with clue upon clue buried in delicate marginal illustrations and spiraling quotations that slow the skimmer and coax the hasty reader into thought. In *Starry Messenger* the mysteries were solvable with the clues at hand. But in *The Tree of Life* the clues are too subtle and too learned. Unless you already know the intellectual history of the nineteenth century, you will lose yourself in the details, like Darwin on the sand path he made at Down House, "thinking, thinking, thinking."

Even the theory of evolution, presented on the book's only foldout, is somehow smothered by the fact that it is expressed in quotations from the heavily coded language of *Origin of Species.* And compared with *Starry Messenger's* bright defiance, *The Tree of Life* has a much more melancholy tone. Galileo under house arrest was freer than Darwin was, in the prison of his own mind. As the pages grow grayer, Darwin turns to investigating the formation of vegetable mold, and becomes increasingly isolated behind his cloak and beard. Sís's Darwin is not for children, I think, but it would make a wonderful gift for the right adult.

Diana Lutz keeps an eye on children's literature for her daughter Emily. She is also the editor of Muse, *a science magazine for children.*

For the Coffee Table

By Laurence A. Marschall

The holiday season is supposed to offer some time for quiet reflection. Gift givers, well aware of the absence of such occasions in their own lives, still imagine that the lives of their friends and family are not so constrained by reality. Here, then, is a highly selective listing for holiday shoppers of some of the finest coffee-table books published in 2003 on science and nature.

The Universe: 365 Days, *by Robert J. Nemiroff and Jerry T. Bonnell (Harry N. Abrams, Inc., June 2003; $29.95)*
Earth from Above: 366 Days, *photographs by Yann Arthus-Bertrand (Harry N. Abrams, Inc., December 2003; $29.95)*

With its uplifting views of space, along with brief commentaries by two veteran astronomers, *The Universe: 365 Days* conveys the immensity and richness of the cosmos. The book's picture-a-day format, with images ranging from amateur snapshots of streaking comets to views of distant galaxies made by the Hubble Space Telescope, provides a better wake-up than a strong cup of black coffee. You can augment each entry with a picture from the book's mother Web site, Astronomy Picture of the Day (http://antwrp.gsfc.nasa.gov/apod/astropix.html), which has been serving up this mind-enhancing fare daily since the mid-1990s.

For an equally stirring view in the opposite direction, try the companion volume, *Earth from Above: 366 Days.* A continuation of the French photographer Yann Arthus-Bertrand's ten-year-long photographic and environmental project (represented in two previous volumes), the book showcases 200 of his new photographs. The aerial images present both famil-

A Celebration of the World's Barrier Islands, *by Orrin H. Pilkey; batiks by Mary Edna Fraser (Columbia University Press, June 2003; $44.95)*

Some 2,200 barrier islands fringe the world's coastlines, but that number is constantly subject to revision. Nibbled at by storms and gobbled up by tsunamis, barrier islands are among the most rapidly changing geological features on Earth. Without frequent replenishment by sand and gravel they can disappear entirely, and new ones are constantly forming. Orrin Pilkey, a professor emeritus of geology at Duke University in Durham, North Carolina, provides an informative guide to the wheres and wherefores of barrier islands—from the vacation meccas off the east coast of North America, to the exotic carbonate archipelagos of Mozambique, to the ice-battered slivers of tundra that line the Arctic Ocean. Aerial and satellite photographs illustrate each geological peculiarity that the text brings into focus, but the most remarkable images in the book are the batiks created

by Mary Edna Fraser. Her overflights of shorelines in the open cockpit of her grandfather's 1946 Ercoupe airplane provided the inspiration for dyed fabrics that capture the delicate shapes and shadings of these evanescent landforms.

[illegible] exotic scenes, but all appear [illegible]sing from the vantage point of a hovering bird (most were shot from helicopters). It is sobering, in some cases, to see how much the hand of man has altered the face of nature.

My Family Album: Thirty Years of Primate Photography, *text and photographs by Frans de Waal (University of California Press, October 2003; $29.95)*

Frans de Waal, a perceptive primatologist and an eloquent writer, has made a career of studying the social

interactions of apes and monkeys in zoos around the world. In three decades of fieldwork he also made, by his own estimate, some 50,000 photographs. *My Family Album* is a sampling of his favorites: 128 elegantly composed black-and-white images that recall the classic pictorialism of the 1920s. His tight focus on faces, made possible because his subjects knew him so well, conveys a genuine sense of intimacy. Most striking of all the features, though, are the eyes. Apes and monkeys make eye contact with each other and with the camera, just as people sometimes do.

In brief paragraphs accompanying the photographs de Waal tells the story behind each look and gesture. He obviously has great love for the apes and monkeys he's known, and his pictures and anecdotes invite the reader to feel, rightly, that primates are members of our own extended family.

Night Visions: The Secret Designs of Moths, *by Joseph Scheer (Prestel, December 2003; $45.00)*

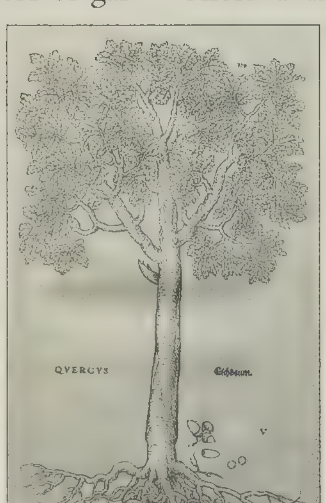
A few pages of technical notes by artist Joseph Scheer on the reproduction of his photographs, along with essays by lepidopterist Marc Epstein and media specialist Johanna Drucker, make up nearly all the text in this mammoth and colorful book. Not much else is needed to accompany its spectacular ultra-close-ups, which showcase the technical virtuosity attainable with digital printing and scanning (the latter at resolutions of 2,000 to 14,000 pixels per inch).

A luna moth, *Actias luna,* whose

wing coloration camouflages it against leaves and stems from a distance, becomes so large on these pages that it looks like a carpet of green grass, covered inexplicably with rich tufts of whitish hairlike scales and two decorative ferns (the moth's antennae). *Euclea delphinii,* a nondescript brown insect, turns out on close inspection to be as soft, plump, and fuzzy as a teddy bear. A copy of this brilliant book on your coffee table will cause as much of a stir as an unshielded porch light on a summer evening.

De Historia Stirpium Commentarii Insignes *(Notable commentaries on the history of plants), by Leonhart Fuchs (Basel, 1542: Octavo Editions, September 2003, CD-ROM ed.; $30.00)*

Few gift givers have the resources to purchase a sixteenth-century herbal for the book collector or gardener on their list. Octavo Editions has the solution. Here, on one compact disk, is a complete facsimile of the first edition of one by Leonhart Fuchs, plus notes and commentary by the botanical historian Karen Reeds. Considered a landmark in scientific illustration when it appeared, Fuchs's book is still highly regarded for the fine detail of its woodcuts. Now, with the magic of modern digital imagery, it is possible to zoom in on every stem of hyacinth, every leaf of gentian. For book collectors with other interests, Octavo Editions (octavo.com) also offers a large variety of rare and highly sought-after titles—from an original Mercator world atlas to Josiah Dwight Whitney's 1868 *Yosemite Book* (the latter includes twenty-eight early albumen prints of one of America's most popular landmarks). All the facsimiles are available, of course, for thousands of dollars less than the paper or parchment originals.



Prehistoric Art: The Symbolic Journey of Humankind, *by Randall White (Harry N. Abrams, Inc., June 2003; $45.00)*

Before there was writing—in other words, for most of humanity's occupancy of this planet—there was art. Buxom figurines of the mother goddess, reindeer antlers incised with hunting scenes, and images of woolly mammoths scratched into the calcite walls of caves endure as records of the sensibilities of early *Homo sapiens.*

But such representations are still deeply mysterious: the mind-set of their creators is so distant, so alien to modern culture, that the temptation is to view them as merely beautiful, or as mere charms to ensure a successful hunt, or as mere expressions of primitive superstition. Randall White, a professor of anthropology at New York University, is a thoroughly literate modern, but he is also an ardent student of ice-age archaeology. His magis-

terial survey of prehistoric paintings and sculptures attempts to evoke the voices of their anonymous creators. The book's handsome color photographs convey beauty and drama, but without such an able interpreter as White, the artworks would not speak authentically for themselves.

Extraordinary Pigeons, *by Stephen Green-Armytage (Harry N. Abrams, Inc., October 2003; $24.95)*

City dwellers regard pigeons as flying rats, creatures whose insatiable appetite for crumbs is matched only by their marksmanship in public defeca-

tion. Yet the pigeon family, Columbidae, is one of the most adaptable avian populations on Earth. So ancient is their domestication that Darwin (who kept a well-stocked dovecote at his country estate) considered the selective breeding of pigeons a paradigm of the evolutionary process.

Stephen Green-Armytage's photographs of avian finery have the chic detachment of high-fashion portraiture: a Jacobin winks coyly from the folds of its hood, like a model wrapped in a feather boa; a white pigmy pouter poses erect and proud, with a puffed-up chest of olympian proportions. Even jaded urbanites will be charmed by the extravagance of these feathered queens.

Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

nature.net

Mars on My Mind

By Robert Anderson

As Mars was making its much-publicized close approach to Earth recently, I often looked up at the southern sky at night and, in my imagination, tracked the Red Planet's movements. No telescope needed: I could see the disk in my mind's eye. I felt its presence. Now, with the imminent landings in January of the two NASA rovers, Spirit and Opportunity, I can imagine myself closer still to Mars—a virtual geologist traversing the rocky terrain of a hostile, alien planet.

Earthbound explorers like me haven't had a show like this since NASA posted the exploits of its 1997 Mars Pathfinder rover, causing, at the time, the biggest "hit blizzard" on a single Web site in Internet history. Once again space buffs can tag along via the space agency's Web site, Mars Exploration Rover Mission (mars.jpl.nasa.gov/mer/overview). Surf the menu bar below the title to acquaint yourself with what's available for your trip at this site. And preview the entire mission through its spectacular series of animations (under the "Multimedia" list, from the menu bar, click on "Video" and then on "Animation").

Before your departure, take a look at how the image of our most alluring celestial neighbor has changed with time. Go to Planet Mars in Popular Culture (humbabe.arc.nasa.gov/mgcm/fun/pop.html), a site put together by David Catling of NASA Ames Research Center, and scroll down through Mars-themed novels, radio shows, and movies. A sister site, Planet Mars Chronology (humbabe.arc.nasa.gov/mgcm/fun/mars_chro.html), offers a time line of the Red Planet's influence on science and culture. To find out how we project ourselves nowadays onto the barren surface of the planet, check out "Face on Mars" and "Cydonia Research," available by choosing the NSF "Archive" page of the e-journal *New Frontiers in Science* (www.newfrontiersinscience.com/index.shtml). Be sure to "Access high resolution animated content" by clicking on the hypertext. For those who daydream of actually setting foot on Mars, I recommend Explore Mars Now (www.exploremarsnow.org). The site's interactive habitat lets you walk around the first Mars "space base," and hints at the difficulties of survival there.

Perhaps the best overall introduction to the planet can be found at Windows to the Universe (www.windows.ucar.edu/). After entering the site, choose "Mars" from the extensive highlighted list. A good place to begin is "Tour Mars!" To dig deeper into the details of the Martian surface, try the clickable atlas (www.roving-mouse.com/planetary/Mars/Atlas/clickable-globe.html). And if there's a place on Mars you've got your heart set on seeing, go to the site of the *Mars Global Surveyor* (mars.jpl.nasa.gov/mgs). The satellite began orbiting and photographing the Red Planet in 1997, and so far has taken more than 120,000 pictures. Yet those photographs cover only about 3 percent of the planet. This past September NASA began taking requests from the public for areas to be imaged, and posting them monthly at the site (look for "Public Requested Image").

The image I found most moving, though (mars.jpl.nasa.gov/mgs/sci/earth/index.html), was not of Mars at all, but showed what the first people living there would see if they looked back at their home planet with a decent telescope.

Robert Anderson is a freelance science writer living in Los Angeles.

Star Baby

T Tauri shows that a stellar nursery can be a rough-and-tumble place to live.

By Charles Liu

Winslow Homer, *Snap the Whip*, 1872

In 1852 the English astronomer John Russell Hind, exploring the constellation Taurus through his telescope, found a dim star that wasn't noted on his charts. The new star, named T Tauri, has since become something of a minor celebrity among astronomers. It owes its fame primarily to its status as a stellar ingenue: it's just a million or so years old, which, for a star about as massive as the Sun, is very young indeed. Nowadays all stars of similar age and mass are known as T Tauri stars; they're immensely important because they afford astronomers a chance to study, by inference, the early history of our own solar system and Sun, born more than four and a half billion years ago.

Astronomers have learned a lot about this stellar baby, the original T Tauri, in the past 150 years. Among the most significant discoveries has been that T Tauri was part of a multiple birth: astronomers identified a second star in the system in 1981 and a third star in 1997. Another study, made early in 2003, suggested that a close encounter between the second and third star, acting as a kind of gravitational slingshot, had hurled the third star out of the system. Now a research team led by Elise Furlan, an astronomer at Cornell University in Ithaca, New York, has discovered that, if the slingshot hypothesis is true, the T Tauri system probably includes a fourth object, too.

T Tauri is about two one-hundredths of a percent the age of our Sun. That's approximately the difference between a baby only a few days old and a middle-aged adult. Although people of both ages are alike in having head, limbs, and torso, their behavior and physical development bear hardly any resemblance at all. Much the same is true for a novice star like T Tauri and a middle-aged star like our Sun.

Like a human baby, a stellar baby is unpredictable. When Hind discovered T Tauri, it was shining at about magnitude ten—roughly one-fiftieth the brightness visible with the unaided eye. In the following forty years, though, the star gradually dimmed by 98 percent, then, inexplicably, it started brightening again. Today it's about as bright as it was when Hind first saw it. The star is still inconstant, however; modern measurements show that, even from one day to the next, T Tauri's brightness can change by as much as half its typical output. Although the causes of the variation remain unclear, the star's interaction with the gassy, dusty environment in which it was born certainly plays a big role.

An infant star, like a baby, also is hungry. T Tauri is so young that the nuclear fusion of hydrogen into helium, which makes mature stars shine, hasn't even begun. Without nuclear fusion, the star's luminosity depends on gravity: matter falling onto the stellar surface from the surrounding gas cloud glows as it accelerates; and the protostellar gas ball, as it collapses inward from its own weight, also becomes hot enough to glow. Plenty of power is generated as a consequence,

enough to make T Tauri shine, but the energy isn't as steady and predictable as nuclear fusion. The thick clouds still swirling around the star further accentuate the swings in luminosity. As T Tauri consumes the matter around it, it grows in mass and in energy output, often spitting up swirling streams of energetic particles called T Tauri winds.

One big difference, though, between human and stellar childbirth is the frequency of twins and triplets. A woman's chances of bearing twins are typically about one in a hundred. But astronomers think that as many as two-thirds of all new stars are born as binaries or multiples. T Tauri was no exception. As I noted earlier, at least three components have been identified, known as North, South-A (the 1981 discovery), and South-B (1997).

Astronomers have long suspected that such systems, with several young stars in close orbit about one another, might occasionally fling one of their components out of the system in a gigantic gravitational game of crack-the-whip. High-precision radio astronomy observations made in early 2001 suggested that the stars in T Tauri were doing just that: South-B seemed to be exiting the system, after having swung around South-A in a curlicue path during the past two decades.

Furlan and her collaborators aimed the 200-inch Hale Telescope, at the Palomar observatory in California, at the system not to investigate the gravitational slingshot, but to study T Tauri's circumstellar environment. (The radio data had not yet been published when the Furlan team began their work.) Using an infrared camera fitted with adaptive optics designed to cancel out the distorting effects of Earth's atmosphere, the astronomers were able to plot the apparent positions of South-A and South-B to accuracies of better than ten milliarcseconds. That's about 1/400,000 of a degree of arc, or the apparent diameter of a penny at a distance of 200 miles. After the radio observations were published, and they compared that data with their own, however, Furlan's group realized that South-B isn't the star moving along the crack-the-whip trajectory after all. It is apparently still orbiting South-A. Nevertheless, the Furlan team doesn't suspect that the earlier data were faulty. On the contrary, they think those measurements actually detected a fourth body in the T Tauri system. That body, tentatively named South-C, is probably being ejected after a close encounter with South-B.

If that interpretation holds up, the gravitational "flinger"—T Tauri South-B—is too faint in radio waves to be detected with radio telescopes,

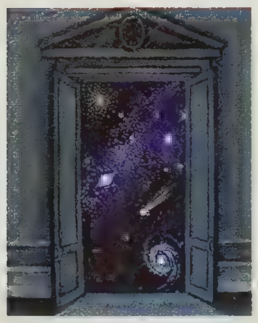
[illegible] the “flingee”—T Tauri South-C—is too faint to be seen in infrared light. What does that say about South-C? One possibility is that South-C isn’t a star at all, but rather a brown dwarf, though it could be an ordinary, low-mass young star.

So imagine, if you will: a bright young star, orbited by two other young stars, all swaddled in swirling clouds of gas and stellar winds, with another large body thrown in—and being thrown out—for good measure. That’s quite a commotion for a star at the dawn of its life.

Charles Liu is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

THE SKY IN DECEMBER AND JANUARY

By Joe Rao



Mercury sets during twilight in December and is barely visible all month. It passes between the Sun and the Earth on the 26th.

In January, however, the planet puts on an excellent show. Mercury is low in the east-southeastern sky at dawn; look for it an hour before sunrise. Find ruddy Antares in the constellation Scorpius; Mercury is below and to the left of the star, and becomes increasingly distant from it as the month progresses. The little planet shines at magnitude −0.2 between the 17th and the 24th and brightens through the rest of the month. Unfortunately, the early morning is brightening as well, making the planet harder to see.

Venus grows progressively more conspicuous in December, a radiant evening “star” in the southwest visible soon after sunset. For observers at midnorthern latitudes, the planet begins the month less than 15 degrees above the horizon at sunset; by New Year’s Eve, though, Venus has shifted to 23 degrees above the horizon at sundown. Binoculars help reveal background stars in the twilit sky as Venus glides past the top of the “teapot” of the constellation Sagittarius during the first third of the month. On Christmas night a slender crescent Moon and Venus make for an eye-catching celestial tableau.

In January, Venus, gleaming at magnitude −4, ascends dramatically higher, its sunset altitude increasing to 33 degrees by month’s end. Seen through a telescope, Venus wanes from nearly full to more definitely gibbous. But the naked-eye view of the planet streaking across half of Capricornus and most of Aquarius as the month progresses is the really exciting spectacle. On the 24th Venus and the crescent Moon virtually replicate their Christmas-night encounter.

Mars, fading after its autumnal glory, is near its highest point in the sky at evening twilight and sets at about midnight. In December the planet, shining south of both Pisces (the fishes) and the square of Pegasus (the winged horse), progresses 15 degrees eastward relative to the two constellations. On the 1st Mars is 79 million miles from Earth and shines at magnitude −0.4; by New Year’s Day the planet has receded 25 million miles more, and dimmed to magnitude 0.2.

Mars declines in brightness again, by another half a magnitude, during January, as the Earth’s smaller orbit further separates the planets. On the evening of the 27th Mars hovers above a fat crescent Moon.

Jupiter rises in the east just after midnight as December begins, and at about 10:15 P.M. by month’s end. It’s shining brilliantly at magnitude −2.1 all month in the constellation Leo (the lion)—about 18 degrees east of Regu-

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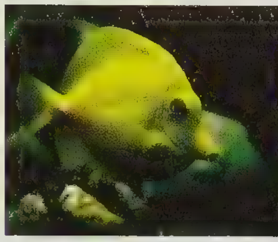

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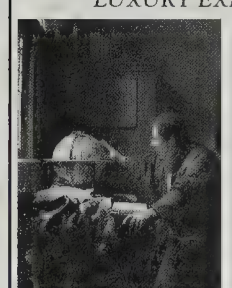

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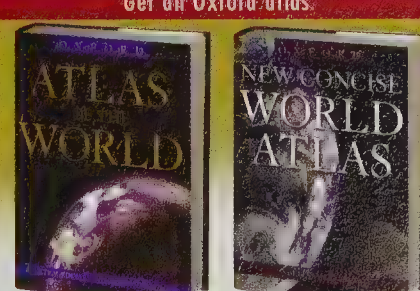

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lus, Leo's brightest star, at midmonth. Regulus precedes Jupiter on their way up the sky by about ninety minutes, but the giant planet is well worth waiting for: even when Jupiter is low in the sky, its four bright moons present an ever-changing dance for the telescope.

In January giant Jupiter rises four minutes earlier with each passing night, and comes up just after 8 P.M. local time by month's end. The planet rises practically due east, and so climbs the sky rapidly as the evening passes—more than 20 degrees in less than two hours. By the end of January it reaches its highest point around 2:30 A.M.

In December Saturn makes its finest apparition in thirty years. It arrives at opposition to the Sun on New Year's Eve, rising as the Sun sets, reaching its highest point in the southern sky at midnight, and setting as the Sun rises. It is also closer to Earth on this night (748.3 million miles) than it has been since another, similar opposition in December 1973. Because of its unusual proximity, Saturn shines as bright as it can ever get: magnitude –0.5. Not until January 2034 will the planet repeat this year's spectacular show. Its rings are dramatically tipped more than 25 degrees to our line of sight: a certain delight for anyone lucky enough to receive a telescope as a holiday gift.

In January Saturn is already well up in the east at sundown and sets in the west-northwest an hour or two before sunrise. The Moon passes to the north of Saturn on the evening of the 6th.

The Moon waxes full on December 8 at 3:37 P.M. It wanes to last quarter on the 16th at 12:42 P.M. and becomes new on the 23rd at 4:43 A.M. It waxes to first quarter on the 30th at 5:03 A.M.

In January the Moon waxes full on the 7th at 10:40 A.M. It wanes to last quarter on the 14th at 11:46 P.M. and becomes new on the 21st at 4:05 P.M. It waxes to first quarter on the 29th at 1:03 A.M.

The Gemenid Meteor Shower should entice even those observers faced with mid-December cold. Now considered the richest of the annual meteor showers (surpassing even the celebrated Perseids of August), the show should peak on the night of December 13–14. You might see as many as 120 "shooting stars" an hour—but expect considerable interference from a waning gibbous Moon toward morning, when the meteor rates are highest.

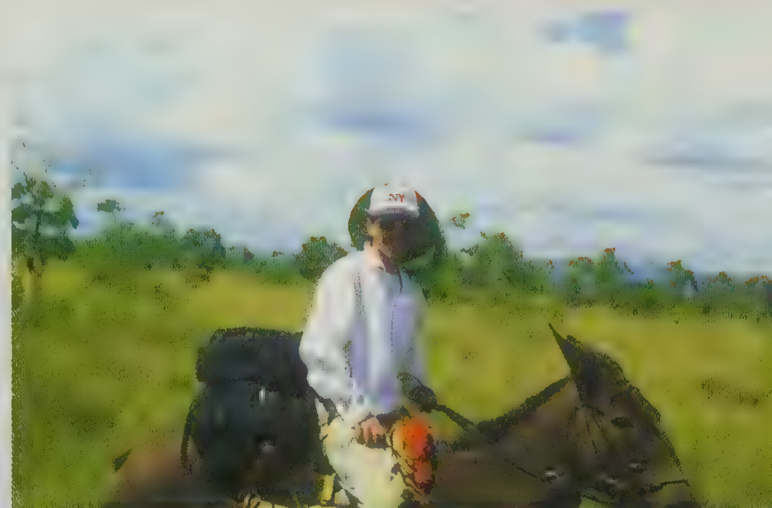
The solstice takes place at 2:04 A.M. on December 22. Winter begins in the northern hemisphere; summer begins in the southern.

The Earth reaches perihelion, its closest approach to the Sun, at 1:00 P.M. on January 4. The Sun is 91,400,172 miles away.

Unless otherwise noted, all times are given in Eastern Standard Time.

Dr. Sacha Spector on Saving "the Other 99 Percent"

Sacha Spector is Invertebrate Conservation Program Manager with the Museum's Center for Biodiversity and Conservation (CBC). We caught up with Sacha in his invertebrate lab at the Museum, as he is busy gearing up for the CBC's March symposium, Expanding the Ark: The Emerging Science and Practice of Invertebrate Conservation.



SERGIO AYZAMA

Sacha Spector doing field research in Bolivia

Q: What exactly are invertebrates, and why should people care about them?

Invertebrates are united by what they *don't* have, namely backbones, rather than any shared features. If you think of the evolutionary "Tree of Life" of animals, vertebrates—mammals, birds, reptiles, etc.—make up only a single branch. All the other animal branches are invertebrates. So invertebrates really represent the vast majority of evolutionary history on Earth. While people mostly think of insects, invertebrates actually encompass a huge range of animals found on land and in water. Some of these we're quite familiar with, like squid, lobsters, corals, and jellyfish, but there's a whole universe of lesser-known invertebrates out there, like tardigrades or "water bears," chitons, and flatworms. As a group, invertebrates probably constitute 99 percent of all animal life on Earth, so we share this planet with millions of invertebrate species.

Invertebrates are essential elements of every ecosystem—they fill niches as herbivores, carnivores, parasites, and decomposers. They also serve as food for mammals, birds, fish, reptiles, amphibians, other invertebrates, and even carnivorous plants! Ecosystem services provided by invertebrates—such as pollination of crops, soil creation and aeration, decomposition, and seed dispersal—are estimated to be worth trillions of dollars to our economy each year. It is said that over one third of the human diet depends directly or indirectly on pollination by insects.

Q: Invertebrates seem to suffer from an image problem...some elicit fear, while others are seen as pests.

Usually, we fear things we don't understand. One of my favorite things is getting kids to look at insects with a microscope—one look at the metallic colors of a beetle or the reflections from a fly's eye and the "eeewww" usually turns into "cool!" As for pests, only a tiny percentage of invertebrates are injurious, and those we're most familiar with are generally non-native species introduced by humans, such as the gypsy moth, Japanese beetle, and some types of cockroaches. But every organism has its function in the web of life—

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Mantis making a meal of a planthopper

even mosquitoes. Mosquito larvae are an important food source for fish and other aquatic creatures, and the adults feed a lot of birds and bats.

Q: What drew you to the study of invertebrates?

My interest in invertebrates hit me later in life. In fact, I went off to college wanting to become a professional trombonist. But I was also very concerned about the environment, and I've always loved the outdoors, so I eventually changed my major to biology. (Also, I quickly realized I would never make a great trombonist.) I did a few insect-related projects as an undergraduate, and the more I delved into biodiversity research, the more I realized that invertebrates were being left out of the majority of conservation efforts. My current research is related to addressing this issue. Because invertebrates as a whole are so numerous and diverse, and most groups are poorly understood, I'm working on designing approaches to choosing a few invertebrate groups about which we can quickly compile as much data as possible, and then use those groups as "information surrogates" for invertebrate conservation planning.

Q: Are invertebrates facing the same threats and endangerment as mammals, fish, and other species?

Absolutely. The three most endangered groups of organisms in the United States—freshwater mussels, crayfish, and stoneflies—are all invertebrates. Widespread threats such as habitat loss, introduced species, and pollution, are rapidly driving many invertebrate species to the edge of extinction. Part of their plight lies in their very diversity—how do you plan and manage communities of organisms when you aren't sure what (or how many) you're dealing with? This is one of the major questions that we will be looking at in the *Expanding the Ark* symposium.

Q: What can we do as individuals to help conserve invertebrates?

There are important things you can do every day. Pesticides, which often kill many other organisms besides the target pest, are a major threat to invertebrates, so one major thing everyone can do is to support farming without chemical pesticides by choosing organic foods. In the suburbs and rural areas, light pollution is a concern as it attracts insects away from their habitats, disrupts their egg laying, mating, and feeding, and also makes them more susceptible to predation. You can reduce or eliminate outdoor lights or, if necessary, install motion detectors or use yellow lights that don't attract insects. But probably the most important thing you can do is to learn about the invertebrates that live in your area. We save what we care about, so the first step is just getting out there and learning to love the fascinating and often beautiful creatures all around us.

MUSEUM EVENTS

EXHIBITIONS


SUBHANKAR BANERJEE

A buff-breasted sandpiper engages in a courtship display

Seasons of Life and Land: Arctic National Wildlife Refuge
Through March 7, 2004
Over 40 large-format color photographs by conservationist Subhankar Banerjee focus on the interdependent relationship of land, water, wildlife, and humanity in Alaska's Arctic Refuge.

Petra: Lost City of Stone
Through July 6, 2004
This exhibition tells the story of a thriving metropolis at the crossroads of the ancient world's major trade routes.

In New York, Petra: Lost City of Stone *is made possible by* ***Banc of America Securities*** *and* ***Con Edison****. The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.*

The Bedouin of Petra
Through July 6, 2004
Photojournalist Vivian Ronay's evocative color photographs document the Bedoul group of Bedouin tribes living near the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 31, 2004
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer.*

Vietnam: Journeys of Body, Mind & Spirit
Through March 7, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the ***Freeman Foundation.*** *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

LECTURES

The Saga of Life
Tuesday, 12/9, 7:00 p.m.
With Nobel laureate Christian de Duve.

Sylvia Earle on Sustainable Seas
Thursday, 12/18, 7:00 p.m.
With the National Geographic Society's Explorer-in-Residence Sylvia Earle.

Petra: Lost City of the Nabataean People
Tuesday, 1/13, 7:00 p.m.
A panel discussion of cross-cultural influences among the many cultures that passed through the ancient city of Petra.

FAMILY AND CHILDREN'S PROGRAMS

Architecture and Archaeology
Saturday, 12/13, or Sunday, 12/14
10:30–11:30 a.m. (Ages 4–6, each child with one adult)
1:30–3:00 p.m. (Ages 7–9)
Astounding Science for Families
Sunday, 12/14, 1:00–2:00 or 3:00–4:00 p.m.
Casting and Model-Making
Sunday, 1/18, 2:00–4:00 p.m.

GLOBAL WEEKENDS

Kwanzaa 2003
Saturday, 12/27, 12:00–6:00 p.m.
This soulful celebration includes activities and performances for the whole family.

Living in America: The Haitian Experience
Saturdays, 1/10, 17, and 31, and Sunday, 1/18, 1:00–5:00 p.m.
Celebrate the 200th anniversary of Haiti's independence with performances, films, and workshops.

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HAYDEN PLANETARIUM PROGRAMS

Lonely Planets
Monday, 12/1, 7:30 p.m.
With David Grinspoon,

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N49, debris from a stellar explosion in the Large Magellanic Cloud

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The Origin of Structure
Monday, 12/8, 7:30 p.m.
With Jeff Hester, Arizona State University.

Virtual Universe
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The Grand Tour
Tuesday, 12/2, 6:30–7:30 p.m.

Our Nearest Stellar Neighbors
Tuesday, 1/6, 6:30–7:30 p.m.

This Just In...
The latest news from the universe.

January's Hot Topics
Tuesday, 1/20, 6:30–7:30 p.m.

Celestial Highlights
Find out what's up in next month's sky.

Winter Sky
Tuesday, 12/30, 6:30–7:30 p.m.

Greek Mythology
Tuesday, 1/27, 6:30–7:30 p.m.

COURSES

Matter and Energy
14 Thursdays, 1/29–5/13, 6:30–8:30 p.m.

Stars, Constellations, and Legends
Five Wednesdays, 1/14–2/11, 6:30–8:00 p.m.

Choosing a Telescope
Three Mondays, 1/26–2/9, 6:30–8:30 p.m.

Introduction to Astronomy
Six Mondays, 1/26–3/8, 6:30–8:30 p.m.

Stellar Death
Five Thursdays, 1/29–2/26, 6:30–8:30 p.m.

Scientific Revolution
Five Thursdays, 1/22–2/19, 6:30–8:30 p.m.

The Science of the Rose Center
Six Tuesdays, 1/13–2/17, 6:30–8:30 p.m.

Pictures to Papers
Four Tuesdays, 1/20–2/10, 6:30–8:30 p.m.

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ENDPAPER

On Thin Ice

By Kirsten Weir

I grew up in rural Michigan, in a house surrounded by woodlands, with a sparkling, spring-fed lake for a backyard. In the autumn the lake reflected the patchwork of reds and oranges from the maple trees that ringed it. In the spring the still surface mirrored the pale green of new buds. The cool water always looked darkest then, dyed by the tannins leached from fallen leaves during the long winter. As warm weather came on, the water cleared.

The lake was our childhood playground, summer and winter; it embodied my sense of the seasons. Each hot day of summer vacation I played and swam in the water until my fingers were wrinkled prunes. When the bitter winter winds blew in, the surface froze to a perfect rink. My sisters and I had strict orders to stay off the ice until my father tested it and pronounced it safe, but from the moment he gave the go-ahead, we'd skate until our toes went numb.

We were (most of the time) obedient children. We never ventured onto the ice until permission was granted. Other creatures were not so patient. One winter a buck fell through the ice.

I don't know who first spotted the struggling deer, but I remember pressing my face against the living-room window that afternoon and watching him thrash about, trying to regain solid ground. He was a large, heavy animal, with an impressive rack of antlers, and each time he heaved himself onto the ice, another chunk of it would break beneath him, plunging him back into the frigid water.

It was clear that the deer was making no progress, so my father called in the "troops." A group of neighbors soon congregated along the shore to assess the situation and work out a plan. After some discussion, my father and a neighbor got out a few shovels and broke up the thin ice around the mouth of the stream that ran into the lake. Then they launched our rowboat, carrying a length of heavy rope. Fortunately the animal was close by, but as the rescuers made their way toward him, the buck made desperate lunges in the opposite direction, smashing through the thick sheet of ice as he went.

The two men fashioned a lasso and, after several attempts, managed to encircle the deer's head with the rope. They coaxed the terrified animal gradually toward the shore, and helped him climb the bank. The rescue operation took more than an hour.

M.A. Hall, *Stag at Echo Rock*, c. 1850

When, freezing and exhausted, he finally felt land beneath his limbs, the buck collapsed. My mother covered him with blankets, and a neighbor phoned the local chapter of the Humane Society for help. When their man arrived, he told us there was nothing for it but to give the deer a quick and painless death.

No one in the rescue party was ready to consign the animal to such a fate. After all, he had put up a magnificent struggle. But it was my father who flatly refused to give in. "You hear that?" he shouted at the buck. "They're going to kill you." He kicked the animal firmly in the rump. "Get on, get out of here."

To our astonishment, the buck got up. Wobbly-kneed, as though he were punch-drunk, he stumbled toward the woods. After a few yards he picked up his pace. Then his gait returned to normal, and he vanished into the trees.

My father died a year ago this spring; a few months after that, my childhood home went up for sale. On a hot, bright July day, my sisters and I took the rowboat to the middle of the lake and sprinkled his ashes into the cool, blue water. We couldn't think of a better way to say goodbye.

Kirsten Weir is a science writer who lives in New York City. She has a degree in biology from Kalamazoo College in Kalamazoo, Michigan, and a master's degree in science journalism from New York University.